PB-245 580

STUDY OF CONCEPTS FOR MINIMIZING EMISSIONS FROM COKE - OVEN DOOR SEALS

H. W. Lownie, Jr., et al

Battelle Columbus Laboratories

Prepared for:

National Environmental Research Center

July 1975

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290016

PB 245 580

EPA-650/2-75-064

July 1975

Environmental Protection Technology Series

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-650/2-75-064	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Study of Concepts for Minimizing Emissions from Coke-Oven Door Seals		5. REPORT DATE July 1975
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) H.W. Lownie Jr. and A.O. Hoffman		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Battelle Columbus Laboratories 505 King Avenue Columbus, Ohio 43201		10. PROGRAM ELEMENT NO. 1AB015; ROAP 21AQR-012
		11. CONTRACT/GRANT NO. 68-02-1439
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Control Systems Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final; 6/74 - 4/75
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The report gives results of a study aimed at minimizing emissions from coke-oven door seals. It identifies problems associated with the sealing of slot-type coke oven end closures, and quantifies them to a limited degree by test results presented in the report. It analyzes coke-oven door sealing systems--those which have been developed in the past, as well as those currently in use--with respect to individual strengths and weaknesses. It develops and critically analyzes concepts to improve the seal design, and recommends the development of the two most favorable concepts.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution	Air Pollution Control	13E
Coking	Stationary Sources	13H
Doors		13M
Seals (Stoppers)		11A

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PRICES SUBJECT TO CHANGE

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 235
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE $7.50

EPA-650/2-75-064

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Contract No. 68-02-1439
ROAP No. 21AQR-012
Program Element No. 1AB015

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Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
WASHINGTON, D.C. 20460

July 1975

EPA REVIEW NOTICE

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Publication No. EPA-650/2-75-064

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The report gives results of a study aimed at minimizing emissions from coke-oven door seals. It identifies problems associated with the sealing of slot-type coke-oven end closures, and quantifies them to a limited degree by test results presented in the report. It analyzes coke-oven door-sealing systems – those which have been developed in the past, as well as those currently in use – with respect to individual strengths and weaknesses. It develops and critically analyzes concepts to improve the seal design, and recommends further development of the two most favorable concepts.

EXECUTIVE SUMMARY

ORIGIN

IN JUNE OF 1974, BATTELLE'S COLUMBUS LABORATORIES WAS AWARDED A RESEARCH CONTRACT TO "STUDY CONCEPTS FOR MINIMIZING EMISSIONS FROM COKE-OVEN DOOR SEALS". THIS CONTRACT WAS FUNDED JOINTLY BY THE ENVIRONMENTAL PROTECTION AGENCY (EPA) AND THE AMERICAN IRON AND STEEL INSTITUTE (AISI), AND WAS MONITORED BY EPA. NINE MONTHS OF TECHNICAL PERFORMANCE WAS FOLLOWED BY REPORT PREPARATION, REVIEW AND CRITIQUE, AND ISSUING OF THIS FINAL REPORT.

SCOPE

THE MAJOR OBJECTIVE WAS TO DERIVE, ORIGINATE, AND EVALUATE PRACTIAL CONCEPTS FOR SIGNIFICANTLY IMPROVED SYSTEMS FOR RETROFITABLE SEALING OF COKE-OVEN DOORS.

PRIOR TO THE AWARD OF THIS CONTRACT, REPRESENTATIVES OF EPA AND AISI DECIDED UPON THE CONTENT OF THE TASKS TO BE COMPLETED AND THE FUNCTIONAL REQUIREMENTS THAT NEW SYSTEMS MUST BE CAPABLE OF MEETING. IN GENERAL TERMS THE RESEARCH TASKS INCLUDED:

- A REVIEW OF EXISTING END-SEAL TECHNOLOGY
- FIELD VISITS AND TESTS TO ASSIST IN DEFINING THE CAUSES OF THE EMISSION PROBLEM
- CONSIDERATION OF POSSIBLE AVENUES OF TECHNOLOGY TRANSFER
- DEVELOPMENT OF CONCEPTS FOR NEW SEALING SYSTEMS

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- DEVELOPMENT OF AN EVALUATION METHOD THAT WOULD TAKE INTO CONSIDERATION THE OPINIONS AND JUDGMENTS OF KNOWLEDGEABLE PERSONNEL IN THE COKE-PRODUCING INDUSTRY AND THE EPA
- DEVELOPMENT OF A METHOD TO MEASURE DOOR-SEAL PARTICULATE EMISSIONS IN ANY FOLLOW-ON DEMONSTRATION PROGRAM.

RESULTS AND CONCLUSIONS

(1) COKE-OVEN DOORS RELEASE PARTICULATE EMISSIONS ONLY BECAUSE THERE ARE GAPS OR UNSEALED SPACES BETWEEN THE DOOR-MOUNTED METAL SEALS AND THE OVEN-MOUNTED JAMBS (DOOR FRAMES). SOME (NOT ALL) OF THESE GAPS "SELF-SEAL" OR ARE DAMMED SHUT BY CONDENSING OF SEMISOLID TARS SOME TIME DURING THE COKING CYCLE. HOWEVER, THIS "SELF-SEALING" PHENOMENON IS INEFFECTIVE IN PREVENTING EMISSIONS, AND COMES AT A TIME IN THE COKING CYCLE AFTER THE MAJOR RELEASE OF EMISSIONS HAS OCCURRED. IT IS NECESSARY TO HAVE TIGHT DOORS PRIOR TO CHARGING OVENS WITH COAL. DOOR AND JAMBS THAT HAVE NO GAPS AT THE SEALS ARE FREE OF VISIBLE EMISSIONS OVER THE ENTIRE COKING CYCLE.

(2) THE DOOR-MOUNTED SEALS OFTEN RECEIVE THE BLAME FOR COKE-DOOR EMISSIONS, BUT THE FUNDAMENTAL CAUSE OF THE EMISSION-RELEASING GAPS IS THE PRONOUNCED DEGREE OF WARPAGE THAT HAS OCCURRED IN

DIFFERING DEGREES ON MOST (IF NOT ALL) OF THE 25,000 OR MORE CAST IRON JAMBS IN OPERATION.

(3) EXISTING METAL SEALS ON COKE-OVEN DOORS WERE NOT DESIGNED TO BE FLEXIBLE ENOUGH TO CONFORM TO (AND THEREFORE SEAL) MORE THAN A MINOR AMOUNT OF JAMB BOWING. INWARD OR CONCAVE BOWING OF JAMBS IS PARTICULARLY TROUBLESOME. HOWEVER, IT IS A CONCLUSION OF THIS STUDY THAT IT IS FEASIBLE TO DESIGN RETROFITABLE, SPRING-TYPE, METAL-DOOR-SEAL SYSTEMS THAT:

- ADJUST TO A DEGREE OF JAMB BOWING FOUR TIMES GREATER THAN EXISTING SPRING SEALS.
- ARE SIGNIFICANTLY MORE RESISTANT TO HEAT DISTORTION THAN EXISTING SEALS.
- CAN ADJUST AUTOMATICALLY TO BOTH JAMB DISTORTION AND DEFLECTION (I.E., ELIMINATE THE NEED FOR MANUAL ADJUSTMENT).

A FOURFOLD INCREASE IN AUTOMATIC INWARD AND OUTWARD SEAL FLEXIBILITY IS REQUIRED TO EFFECTIVELY SEAL MOST OF THE JAMBS IN OPERATION. INCREASED HEAT RESISTANCE OF THE SEALING SYSTEM IS REQUIRED BECAUSE GAP-FORMING THERMAL DISTORTION OF NEW METAL SEALS HAS BEEN OBSERVED IN LESS THAN 3 MONTHS OF OPERATION.

(4) FORTY-FIVE CONCEPTS FOR NEW DOOR-SEALING SYSTEMS WERE DEVELOPED BY METHODS AND APPROACHES DESCRIBED IN THIS REPORT. THESE CONCEPTS WERE EVALUATED IN STAGES. DURING BATTELLE'S FINAL EVALUATION, CONSIDERATION WAS GIVEN TO (A) THE JUDGMENTS AND

COMMENTS MADE BY THE AISI AND EPA REPRESENTATIVES DURING A PRELIMINARY EVALUATION, (B) THE TECHNICAL SPECIFICATIONS THAT BATTELLE RESEARCHERS JUDGED THAT NEW SEAL ELEMENTS MUST MEET, AND (C) THE FUNCTIONAL REQUIREMENTS SPECIFIED BY THE SPONSORS.

(5) IN A SYSTEMATIC CONSIDERATION OF THE TECHNICAL SPECIFICATIONS AND FUNCTIONAL CRITERIA, BATTELLE RESEARCHERS GAVE A "PROBABLE" RATING ONLY TO CONTACT SEALS, I.E., TO SIGNIFICANTLY UPGRADED METAL SEALS. THIS "PROBABLE" RATING PREDICTS A 90 TO 100 PERCENT PROBABILITY OF SUCCESSFUL DEVELOPMENT AND PERFORMANCE IN MEETING ALL OF THE CRITERIA DEVELOPED AND SPECIFIED.

(6) A "POSSIBLE" RATING (40 TO 90 PERCENT PROBABILITY OF SUCCESS) WAS GIVEN TO VARIATIONS OF LUTED SEALS DESCRIBED IN THIS REPORT AS THE APPLICATION OF FOAMED-IN-PLACE SEALANTS EITHER BETWEEN THE MATING SURFACES OR INJECTED INTO THE GAS PASSAGE AFTER A DOOR HAS BEEN MOUNTED ON AN OVEN. THIS RATING INDICATES THAT RESEARCHERS HAVE RESERVATIONS ABOUT THE ABILITY OF LUTED-SEAL CONCEPTS TO MEET SEVERAL OF THE TECHNICAL SPECIFICATIONS. IN CONSIDERING THE DEVELOPMENT OF THIS APPROACH, THERE ARE UNKNOWNS THAT CAN BE EVALUATED ONLY IN AN EXPERIMENTAL PROGRAM. ALL OTHER CONCEPTS AND CONCEPT FAMILIES WERE GIVEN LOWER RATINGS.

(7) THE DEVELOPMENT OF A COKE-DOOR EMISSION-TEST METHOD TOOK THE PATH OF ENCLOSING A COMPLETE COKE-OVEN DOOR WITHIN A SEALED HOOD AND PASSING THE

EXHAUST THROUGH A FILTRATION UNIT TO COLLECT PARTICULATES. THE METHOD WAS TESTED SUCCESSFULLY ON AN OPERATING COKE-OVEN DOOR.

(8) OVERALL, IT WAS FOUND THAT THERE HAS BEEN VERY LITTLE TECHNICAL EFFORT WITHIN THE COKE-PRODUCING INDUSTRY TO COLLECT AND ANALYZE BASIC DATA RELATING TO THE CONDITIONS, PERFORMANCE, AND PROBLEMS OF COKE-OVEN END CLOSURES OF WHICH DOORS AND JAMBS ARE A PART. THIS IS THE REASON FOR THE WIDE DIFFERENCES OF OPINION THAT EXIST ON THIS SUBJECT. THE EFFORT MADE IN THIS RESEARCH PROGRAM TO DEFINE THE PROBLEM REPRESENTS ONLY A START OF WHAT BATTELLE BELIEVES IS REQUIRED IN THE WAY OF TECHNICAL ANALYSES. FURTHER STUDY AND ANALYSES ARE NECESSARY TO AID IN RATIONAL DEVELOPMENT OF EFFECTIVE NEW SEALING SYSTEMS.

RECOMMENDATIONS

(1) MORE-FLEXIBLE AND MORE HEAT-RESISTANT METAL SEALS SHOULD BE DEVELOPED FURTHER IN A FOLLOW-ON PROGRAM. DESIGN WORK SHOULD BE PRECEDED BY EXPERIMENTAL EFFORT TO ANALYZE THE TEMPERATURE DISTRIBUTION AND THERMAL-STRESS PATTERNS IN EXISTING SYSTEMS AND DESIGNS. THESE ANALYSES WOULD SERVE AS VALUABLE INPUTS TO THE DESIGN AND MATERIAL-SELECTION PROCESS AND WOULD ALSO SERVE AS A BENCHMARK FOR EVALUATING THE PROJECTED PERFORMANCE LIFE OF DESIGNS FOR NEW SYSTEMS.

(2) BECAUSE THE BASIC EMISSION-CAUSING PROBLEM IS THE DISTORTION THAT HAS OCCURRED (AND IS CONTINUING) AT OPERATING JAMBS, THE FACTORS CAUSING THIS PROBLEM SHOULD BE ANALYZED QUANTITATIVELY. A TECHNICAL ANALYSIS SHOULD INDICATE WHAT STEPS CAN BE TAKEN IN DESIGN AND MATERIALS TO DEVELOP A MORE DIMENSIONALLY STABLE JAMB FOR BOTH NEW COKE-OVEN BATTERIES AND REPLACEMENT OF SOME JAMBS AT EXISTING BATTERIES.

(3) BECAUSE THE CONCEPT OF USING SEALANTS OF SOME VARIETY BETWEEN THE DOOR AND THE JAMB SURFACE HAS THE POTENTIAL FOR TOTALLY ELIMINATING DOOR EMISSIONS, THE APPLICATION AND PERFORMANCE OF VARIOUS SEALANTS SHOULD BE TESTED IN A LABORATORY ARRANGEMENT.

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CHAPTER I

INTRODUCTION

This is the Final Report prepared by Battelle's Columbus Laboratories concluding a 9-month study and research program entitled "A Study of Concepts for Minimizing Emissions from Coke-Oven Door Seals". The work reported herein was sponsored by the Control Systems Laboratory of the Environmental Protection Agency (EPA) and by the American Iron and Steel Institute (AISI). The opinions, evaluations, judgments, and recommendations expressed are strictly those of the participating Battelle-Columbus staff.

Background and Antecedents

In January of 1970, Battelle-Columbus issued a formal report on coke-plant emissions control to the National Air Pollution Control Administration.(1) This report was the first step in defining and reviewing the vast problem of curtailing airborne emissions from coke ovens. Battelle researchers recommended that the solution to air-emission problems, which all coke-oven operators have in common, can best be achieved by group action and joint contributions. At that time, joint action was in its early stages, and later was expanded to include both technical and funding contributions by both EPA and AISI. The present project is another example of combined effort toward a common goal.

---

(1) "Final Report on Evaluation of Process Alternatives to Improve Control of Air Pollution from Production of Coke", by T. M. Barnes, A. O. Hoffman, and H. W. Lownie, Jr.; prepared for the Division of Process Control Engineering, National Air Pollution Control Administration, United States Department of Health, Education, and Welfare under Contract PH 22-68-65. Available from the National Technical Information Service as Document PB 189266.

In January of 1974, the Battelle-Columbus Laboratories responded to an EPA Request For Proposal (EPA RFP No. DU-74-A039) dealing with a research program to study, innovate, and evaluate concepts for minimizing emissions from coke-oven door seals. It was understood that the research was to be sponsored and financed jointly by EPA and AISI and that the research was to be monitored by EPA.

The contract for this research was awarded to Battelle-Columbus in June, 1974. The stated period of performance included 9 months of technical effort to be followed within 30 days by the submission of a Proposed Final Report for review by the Sponsors. This Final Report is the result of the technical effort and the review of the Proposed Final Report which was dated March 26, 1975.

Scope and Purpose

The scope of work as stated in the joint contract with EPA and AISI was as follows:

> "The Contractor shall undertake a scientific and engineering investigation to define technology to eliminate emissions due to leakage from slot type coke oven and closures. The product of the investigation will be technical descriptions of one or more clearly defined techniques to meet the above objective with background information sufficient to support future full scale demonstration work."
>
> "The technique or techniques recommended must be capable of meeting, to the greatest extent possible, the following functional description:
>
> 1. Capable of being retrofitted to all current and contemplated slot-type coke ovens, encompassing all oven heights and construction types.
> 2. Compatible with existing door handling and oven end working machinery.
> 3. Operability and reliability commensurate with present coke oven practice.

> 4. Dependability and repeatability of operation.
> 5. No creation of additional or different environmental problems.
> 6. No adverse effects on product quality.
>
> In order to meet the project objectives, it is expected that the investigation consider the basic problems associated with coke oven end emissions and examine past and present attempts to control this source or similar sources. Using this background information, conceptual schemes for meeting the objectives can be brought to a point where actual technological development can be initiated. It is not anticipated that construction or testing of individual conceptual schemes will be required in the present investigation. However, if fabrication of a seal section or component for shop testing is necessary to establish the practicality of a particular concept, such work shall be performed."

The major purpose of the research program was to derive and originate practical concepts on which further research/engineering and testing of improved coke-oven seals can be soundly based. As part of the project input, Battelle-Columbus was expected to review existing end-seal technology, to consider possible avenues of technology transfer, and to develop a critique method that would take into consideration the opinions and evaluation (of concepts) of experienced coke-plant superintendents and EPA personnel.

In addition, the scope included development of a method for measuring door-seal emissions. The purpose of this task was to provide a basis for future evaluations of the performance of different end-seal configurations in any follow-on demonstration project.

In accordance with the EPA Request For Proposal, the study was divided into six tasks. The timing of these tasks overlapped and most were conducted, at least partially, simultaneously. This report follows, in general, the sequence of tasks as defined in the Contract. The identifications of the Tasks were as follows:

"1. Problem Definition – Conduct an analysis to determine the conditions which effect emissions from oven end seals. Various battery sizes and configurations both in current use and contemplated shall be considered. Techniques such as interviews with plant operators, literature surveys, and in-plant measurements may be utilized to define the problem.

2. Review of Existing End Seal Technology - Catalogue and analyze various sealing schemes that have been put into practice and/or proposed. The schemes shall be defined by means of literature reviews, industry interviews, in-house information, or other means at the disposal of the contractor.

3. Review Potential Technology Transfer - Define other technical areas which have similar sealing requirements.

4. Develop Conceptual Methods - Based on the background information developed above, develop concepts for sealing techniques to meet the functional goals of the system. For the more promising systems, prepare conceptual engineering drawings and working descriptions adequate for further analysis and development.

5. Develop Test Methods - In order to secure useful information from the follow-on demonstration effort, it is necessary to develop methods for measuring door seal emissions or (as a minimum) methodology for comparing the performance of different door seal configurations.

6. Critique of Conceptual Ideas - Prepare a critique of each system developed in 4 above. The critique should address itself to the functional goals of the system and should define the specific problems to be overcome for the scheme to operate successfully."

Early in this program, the Chairman of the AISI Task Force on Coke-Oven Door Seals polled the AISI coke-producing plants to determine (a) whether individual plants had any information, data, or contributions to make to this program and (b) whether each plant was willing to have a visitation by the Battelle-Columbus researchers. It is understood that all plants were willing to have research visitors and several plants requested a visitation. Contact was established with most coke-producing companies, and visits and return visits were made to those plants that were in a position to contribute important information dealing with the objectives of this program.

Some individual plants are experimenting with improved end-seal closures, mainly in terms of adding elastomeric or refractory-type guard seals either inside or outside the primary, standard metal-to-metal seal. The results of these programs were examined and evaluated.

Research Staff

The Battelle-Columbus professional staff most directly concerned with major inputs to this study included the following:

H. W. Lownie, Jr., Program Manager
A. O. Hoffman, Project Leader
J. M. Allen
J. J. Grimm
R. E. Maringer
R. L. Paul
J. B. Purdy
E. E. Reiber
J. Varga, Jr.

The Sponsorship personnel most directly concerned with this study were:

Mr. John G. Munson, Jr., Chairman, AISI Task Force on Coke-Oven Door Seals
Mr. Calvin Cooley, AISI Headquarters, Washington, D.C.
Mr. Richard D. Rovang, Project Officer for EPA
Mr. George G. Bennett, Contract Administrator for EPA
Mr. M. P. Huneycutt, Contracting Officer for EPA.

Special Acknowledgments

Early in this program it became apparent that many coke-plant superintendents were much interested in contributing their experience, thoughts, and time to this program. This helpful attitude and the resulting inputs were of great assistance in reaching the objectives of this program. These individuals chose not to be mentioned by name or affiliation, but Battelle-Columbus researchers appreciate their extra effort on behalf of this program.

The number of "other contributors" is large and is, therefore, not included. However, this problem-solving program attracted the interest and the contributions of other Battelle staff members experienced in many fields and based in two of Battelle's research laboratories. To these "other" contributors, we also express appreciation.

Qualifying Statements

Some of the comments and judgments in this report could be construed as being critical of the door-sealing designs and approaches of the builders of coke batteries. In this regard, it should be appreciated that (a) Battelle has been working toward a new set of performance standards, i.e., what was good then is not acceptable now; (b) Battelle has been working in what is a hindsight position relative to the designers and builders of existing seals; and (c) builders may be actively developing their own designs for future ovens. If they are doing so, these designs were not revealed to Battelle researchers.

In hindsight, everyone can recognize mistakes or compromises that were not effective. In this regard, it should be recognized that the concepts presented in this report are aimed at retrofitability, which may or may not be an objective of coke-oven builders. Battelle researchers hope that coke-oven builders will review this report and will make known to our Sponsorship (and Battelle) any errors or omissions that they deem important. Battelle takes the position that all viewpoints should be considered in solving this air-pollution problem.

A group of steel-industry coke-producing experts known as the Task Force on Coke-Oven Door Seals of the AISI Technical Committee on Coke-Oven Practice, along with cognizant staff members of EPA, assisted Battelle researchers in the review and evaluation of concepts and in a review of this report in its proposed final form. The efforts of all reviewers are acknowledged with thanks. However, their participation and assistance should not be construed as approval of or concurrence with findings and recommendations expressed in this report. The judgments and conclusions are to be regarded as Battelle's contribution and responsibility.

CHAPTER II

SUMMARY AND RECOMMENDATIONS

Based on data and conceptual inputs derived and collected from sources within Battelle and within the coke-producing industry, Battelle researchers selected the 45 concepts described and presented in this report. These were then classified into six concept families (concepts with a common base) and each family was evaluated. As a first step, evaluators from EPA, AISI, and Battelle met at Battelle-Columbus and by joint action developed an ordered and ranked list of 15 criteria for use in the evaluation process. Evaluation of the concept families was then completed privately by each individual evaluator using a weight of 1 through 5 for each criteria for each concept family. The total score for any one concept family was the sum of the multiplications of ranking and the weighting.

Overall, the results of the combined evaluation/critique did not indicate any outstanding preference or consensus. However, three concept families were rated low by all groups of evaluators.

This judgmental evaluation was followed by continued research effort to gain further insights into the practical aspects of the various concept families. In this effort, the comments of the AISI and EPA representatives gave the researchers useful inputs. Battelle's final evaluation was based on seven technical specifications derived by Battelle plus the six functional requirements specified by the Sponsorship. The seven technical specifications are summarized as follows:

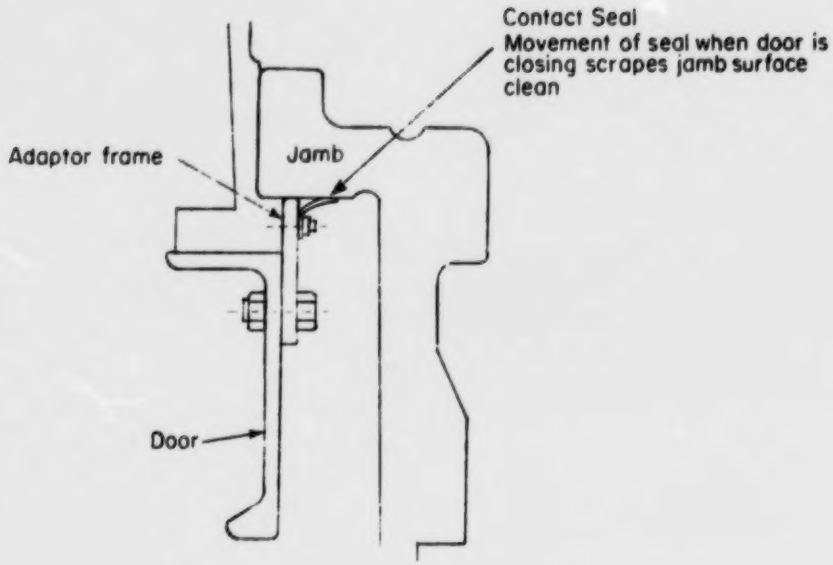
- Must withstand the 200 to 315 C (400 to 600 F) temperature pattern in the seal location for prolonged periods of time.

- Must withstand occasional short periods of up to 430 C (800 F) without being destroyed.
- Must have automatic gap-closure capability; i.e., no need for manual adjustment of any kind.
- Should have increased gap-closure capability (up to four times that of existing seals).
- Must be resistant to corrosion and chemical attack.
- Must be total-failure proof; i.e., must not be susceptible to the possibility of complete and/or sudden failure during operation.
- Should not introduce new cleaning problems that are not clearly solvable.

Results of Battelle's Final Evaluation

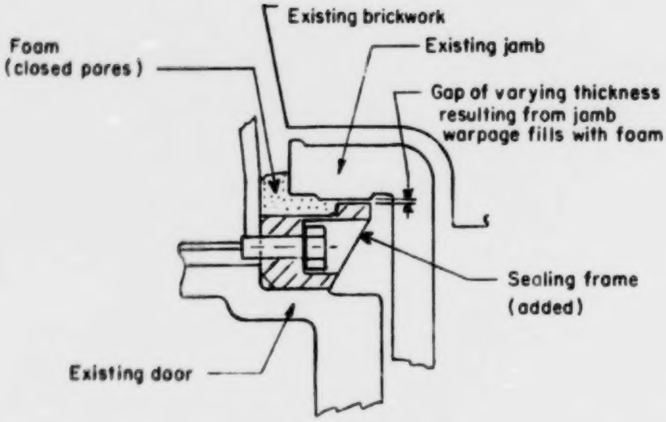
In the final evaluation of the six concept families described in this report, Battelle researchers gave only one family a "probable" rating (90 to 100 percent probability of overall successful development and performance) in each of the technical specifications and functional requirements. This preferred-concept family is that of metal contact seals. These would be upgraded versions of existing metal contact seals. Stated another way, Battelle researchers believe that (a) existing sealing systems (although often called inadequate) are really marginally successful and can be greatly improved, and (b) there is no other concept or concept family that approaches this sealing approach in terms of probability of successful performance in this difficult and hostile environment.

A stylized sketch of one of the contact-seal concepts, taken from the family of contact seals shown in Chapter VI, is as follows:


Contact Seal
Movement of seal when door is closing scrapes jamb surface clean
Adaptor frame
Jamb
Door

A technical evaluation of the family of metal contact seals in terms of increased sealing flexibility, adaptability, and improved heat resistance established to Battelle's satisfaction that this approach is feasible (Chapter VII). Overall, it is judged that this concept family has the greatest potential for successful development of an effective and broadly acceptable oven-door-sealing system.

Only one sealing concept was rated as "possible" (40 to 90 percent probability of overall successful development and performance). This "possible" rating was given to "luted seals". In this report the luted-seal family includes the applications of foamed or unfoamed sealants placed on the jamb or door before a door is mounted on an oven, and also includes foaming materials that are injected into the gas passage after the door is mounted on the oven. A stylized sketch of one of the luted seals is as follows:



The luted-seal concept had appeal to evaluators representing the AISI and EPA. Battelle researchers are also aware that sealants have the potential for completely eliminating emissions from coke-oven doors. In addition, there is a possibility that a simple procedure for foam sealing of doors could be developed. However, this remains only a possibility at this time and was rated as such. Battelle's reservations were on the technical-specification points of increased gap-closure capability and avoidance of new cleaning problems. Also, there were reservations in the functional requirement relating to dependability and repeatability. The only way possible to evaluate and/or bypass the uncertainties of this luting approach would be through a laboratory testing program or through a combined laboratory and coke-plant testing program.

It is a well known and demonstrable fact that the contact seals as represented by existing doors today do not truly seal emissions through intimate metal-to-metal contact. When doors are emission free, sealing has been accomplished through the contact with deposits condensed at the sealing surfaces. In a broad sense, the fluid and/or semisolid deposits can be thought of as luting compounds. Using this idea, today's contact seals are "self-luting seals". Ultimate sealing capacity for contact seals (developed according to the recommended contact-sealing approach) might require a luting compound. Therefore, if development of sealing devices according to the recommended concept should prove eventually to be less sucessful in sealing emissions than required, development of luted seals would be a logical and rational continuation of the development effort.

Cause of the Coke-Door-Emissions Problem

Investigation of the causes of visible emissions from coke-oven seals shows that the door-mounted seals receive the blame for emissions, but that the fundamental cause of the problem is the continuing thermal warpage and distortion of the cast iron, oven-mounted jambs. While there are also design and warpage problems in existing door-mounted seals, the degree of warpage on many jambs is in excess of the limits that some existing seals have been designed to handle. Emissions are the result of gaps between sealing edges and the warped jambs; i.e., gaps that either are not filled with previously deposited tar sealants or are only slowly filled with tar sealants during the coking cycle. The fact that gaps are only slowly dammed or filled is a result of the varying composition of the gases and vapors reaching the seal location and the varying condensation rate of the tars on the jamb surfaces. During the period of high internal pressure at the beginning of every coking cycle, the major portion of the gases reaching the jambs is steam. This steam content does not permit rapid self-sealing of gaps by the tar component of these gases. Later in the coking cycle, higher-boiling-temperature tars reach the jambs and seal areas and the steam content is lower. Self-sealing of gaps is rapid near the bottom of ovens where the jamb is cooler and is slower at the top of the oven where the jamb is hotter.

It is judged, however, that replacement of the unknown number of jambs that are warped excessively with new jambs of conventional design is not a solution to this problem. It is not a solution because new jambs would promptly begin to warp. This judgment was taken into consideration by Battelle researchers in presenting their recommendations.

Development of Emission-Test Methods

The objective of this portion of the research program was to develop the equipment and a method for measuring the amount of particulate emissions from coke-oven seals. This equipment and procedure forms a basis for techniques to be used in the evaluation of new seals developed in any follow-on program.

The principle selected for collecting emissions involves a sealed hood placed over a complete coke-oven door with an exhaust leading to a filtration unit to collect particulates. Although this basic principle may have some inherent disadvantages for prolonged collection of emissions, it does lend itself to a quantitative measurement (by weight) of coke-oven-door emissions during the early portion of a coking cycle. The EPA has an interest in further development of this equipment to collect all of the emissions and gases over an entire coking cycle. However, there is concern over the increase in temperature of the door resulting from the full-time hooding of the door. Further development work on this aspect is being separately funded by EPA.

For the purposes of the present program, the selected equipment and method of measuring emissions were demonstrated at a commercial coke plant. It was concluded that the equipment and method can be used to measure quantitatively the particulate emissions from experimental coke-oven-door seals in any follow-on project.

Recommendations for a Follow-On Approach and Program

This section deals with Battelle's recommendations and suggestions for a follow-on approach and a follow-on program.

Introductory Comments

A point of view, or relative position, is inherent in all things involving judgment or a difference of interest. Battelle's point of view places emphasis on developing a rather detailed technical definition of any problem so that subsequent work can be completed rationally. From this viewpoint, it is Battelle's suggestion that additional research/investigation/analysis should be completed prior to beginning the design of contact seals. The technical causes of coke-door emissions are more complex than is readily apparent.

Other points of view are based on differences in interest, approach, and background. Battelle does not discount other points of view and hopes that every possible approach is taken to the solution of the problem. For example, another point of view might be:

"Call it empirical if you want, but let's attack the problem by building test doors – see what happens then go from there". This approach could give fast results and Battelle hopes that companies will assign additional technical personnel to such projects to attempt to get fast results. However, empirical approaches do not lend themselves to extrapolation nor do they contribute to developing answers to such questions as "If it works at Plant A, why doesn't it work at Plant B"? Regardless of the various approaches that will be taken, Battelle suggests that continued technical analysis would contribute significantly to the solution of the problem. Battelle's recommendations are presented from this point of view.

Recommendations

Battelle's major recommendations concerning a follow-on approach/program are as follows:

(1) Because the door-emissions problem is both urgent and serious, it is recommended that research/ development of new, retrofitable metal contact seals should be emphasized. This approach is expected to seal most, if not all, of the existing warped jambs in the coke-producing industry. This program should be taken to the point of demonstration, and should be followed by the preparation of retrofit specifications and operational manuals. The beginning of the design phase should be preceded by a technical program designed to analyze the stresses, temperature fluctuations, and dimensional shifts of existing end-closure components. It is suggested that a comparison of the operating stress level in new seals with existing baseline conditions will indicate whether the new seals will have a superior longevity. This approach should eliminate the need for prolonged testing to establish seal life.

(2) Because the real cause of the coke-door emissions problem is the warping of the door jambs, it is recommended that research be directed to quantifying and analyzing the factors causing this warpage. This investigation should produce recommendations of materials/designs/procedures that will result in

dimensionally stable jambs for (a) new ovens, and (b) replacements, and probably for upgrading existing jambs.

(3) Because luted seals (of one kind or another) have the possibility of completely eliminating door emissions, it is recommended that a laboratory/plant exploratory experimental program be initiated to define further the problems and possible solutions. It is suggested that if there is demonstrable progress, the entire approach (luting) should then be evaluated in a feasibility/cost/benefits analysis relative to the progress being made in development of metal contact seals.

CHAPTER III

REVIEW OF THE EVOLUTION OF PERTINENT COKE-MAKING TECHNOLOGY AND COKE-OVEN SEALS

Various factors in the production of coke have a direct influence on the problem of leaking coke-oven doors. This chapter provides some information concerning these factors, as well as historical background on the development of coke-oven doors and door seals.

Pertinent Coke-Making Technology

The features of coke manufacture in coke ovens that can influence the leakage of coke-oven doors can be divided into two groups: (1) those that relate to operating practice, and (2) those concerned with gas evolution during coking.

Coke-Making Operating Practice

The first by-product coke ovens were placed in operation in the United States in 1892 at Syracuse, New York. (1)* The early coke ovens were not charged to their full volume as is the normal operating practice today. Leveling mechanisms had not as yet become part of pushing machines. Coal charged into an oven found its natural angle of repose as shown in Figure III-1. (2) The coal was charged in this manner to minimize the formation of "black ends" (or what is known today as "green coke") because of the location of the end flues as shown in Figure III-2. (2) Subsequent evolution of design of coke-oven doors is discussed later in this chapter.

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*References are at the end of the chapter.

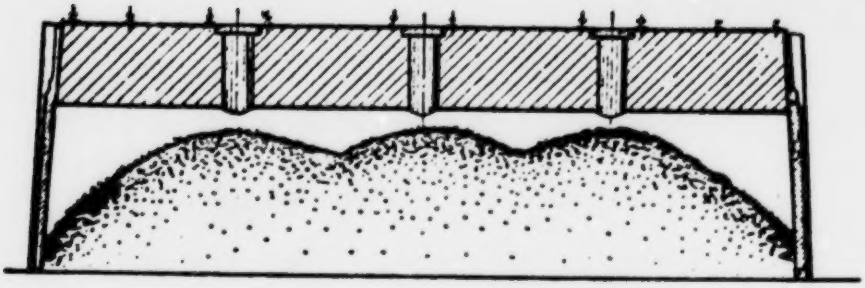

FIGURE III-1. EARLY METHOD OF CHARGING COAL TO COKE OVENS

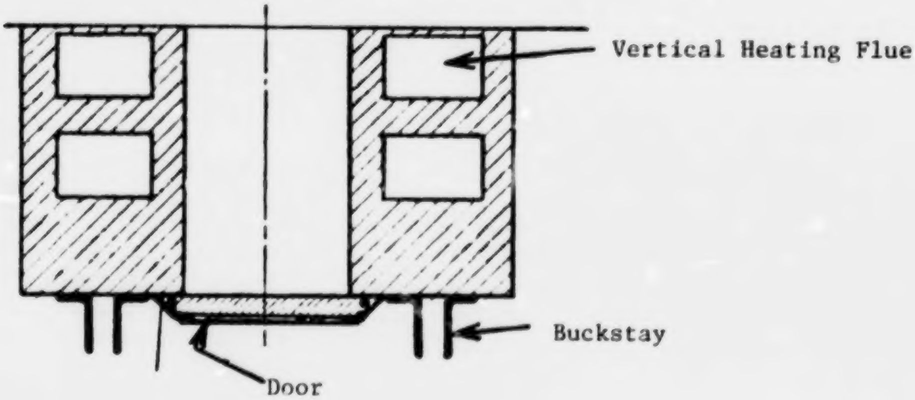

FIGURE III-2. LOCATION OF END FLUES IN AN EARLY COKE OVEN

Horizontal cross section.

Maintaining the "free space" above the charged coal is an important factor in minimizing gas pressure within a coke oven. The "free space" is illustrated in Figure III-3, which is approximately to scale for a 4-meter (13-foot) oven. The "free space" is about 0.3 meter (1 foot) high and is that space available for gas flow between the leveled coal and the roof of the oven. This space must be kept open to allow passage of the gases from the coking coal to the ascension pipe and on into the collecting main. If for any reason an oven is charged with coal in excess of the optimum volume, the excess coal will result in a decrease in the volume of free space with an accompanying restriction to the passage of gases and a resulting increase in gas pressure. This situation may be overcome if the steam-aspiration system has the capability of increasing suction in the ascension pipes. Overcharging of an oven may also result in forcing coal into the bottom of the gas offtake to the ascension pipe. Because of the high temperatures at this location in the oven, small amounts of coal may fuse to the hot refractory lining the gas offtake, resulting in restriction of the gas passage and causing increased back pressure in the oven.

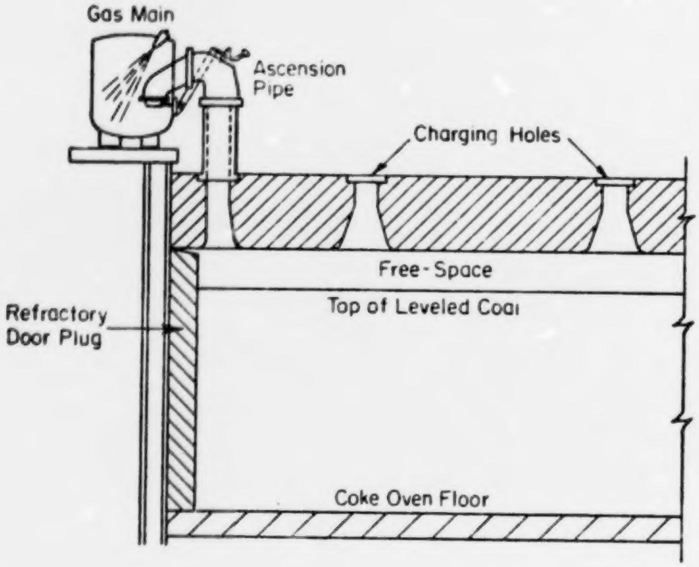

FIGURE III-3. LOCATION OF "FREE SPACE" IN A BY-PRODUCT COKE OVEN

During the coking cycle, carbon can build up on the roof of the coke oven and cause a decrease in available free space and, again, an increase in oven gas pressure. This is a particular problem at some plants. The carbon forms in fine filaments hanging down from the roof (similar to stalactites formed on the roof of a cave) and can severely lower the volume of free space. Removal of the roof carbon is usually done by allowing the oven to remain empty with the doors on the oven. One or more charging-port lids are usually opened a small amount to permit air to enter the oven and to burn the roof carbon. During these periods the coke-oven doors are exposed to high temperatures in the range of about 925 C to 1150 C (1700 to 2100 F). It is believed that if this decarbonization period is prolonged, it can result in warpage of the jambs and door seals on an oven.

Evolution of Gases

Factors that contribute to the problem of keeping coke-oven doors leak-tight are the larger-than-average generation of gas at the start of the coking cycle, coupled with the restrictions in the upward flow of gas through the coal. This combination of high gas volume and restriction to flow results in the development of relatively high gas pressure at the door seals.

The amounts of gas generated throughout the coking cycle for different coking times are illustrated in Figure III-4.(3) In referring to Figure III-4, it should be noted that the gas-flow rates for coking times of 15 to 17 hours (the usual range for blast furnace cokes) vary between 40 and 60 cubic meters per minute (25-35 cubic feet per

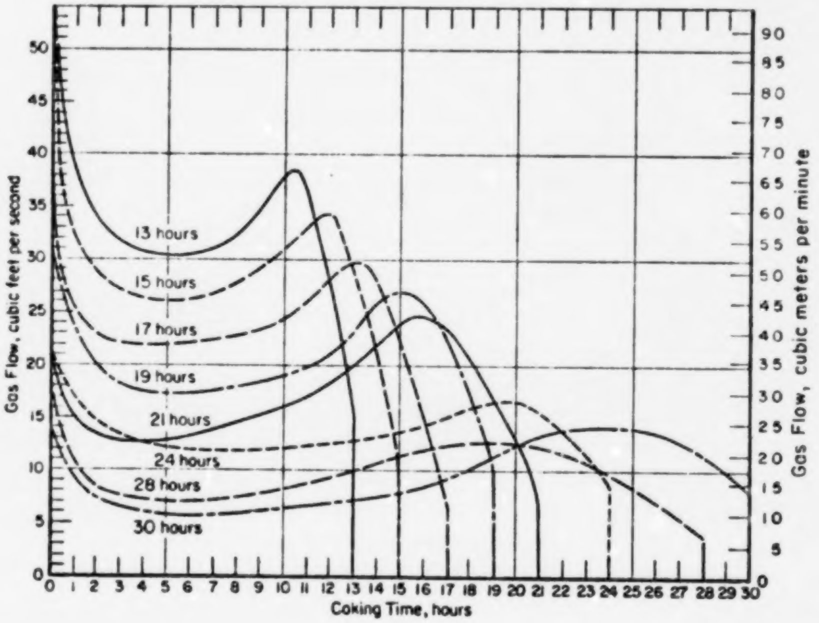

FIGURE III-4. GAS FLOW DURING BY-PRODUCT COKING FOR VARIOUS NET COKING TIMES

second) during most of the coking cycle. The period of highest pressure is at the start of the coking cycle, during which time gas pressures in the coke-oven-door gas channels have been reported to peak as high as 710 mm of water (about 28 inches of water or about 1 psi). The time-pressure relationship for this unusually high-pressure peak is shown in Figure III-5.(4) The high-pressure peak may correlate with a brief but unusually high volume release of gas just after charging. However, it is suspected that the pressure in the gas passage is elevated at the beginning of a coking cycle because of the inability of the gas to flow upward through the finely pulverized coal. With a restricted upward flow of gas through the coal, gas can flow laterally in high volume into the gas channels. This lateral flow continues until the coal against the heated wall cokes and develops fissures. Once fissures have developed, numerous paths are open for the gases to travel up the coke/coke-oven wall interface, resulting in a drop in pressure in the gas channel.

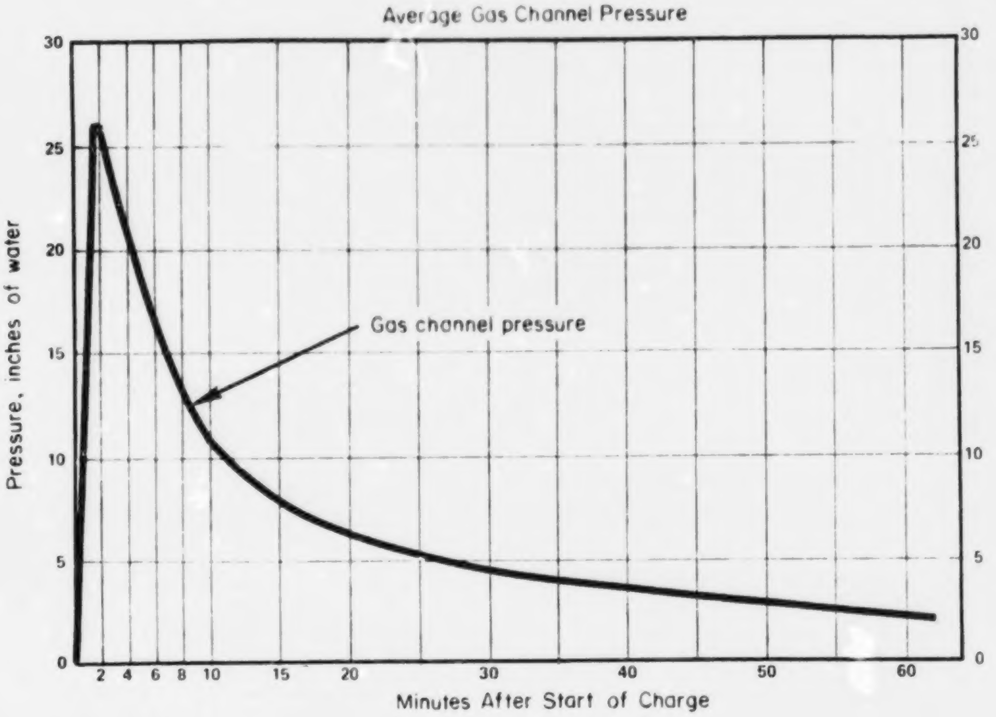

FIGURE III-5. REPORTED VARIATION IN GAS-CHANNEL PRESSURE OVER THE FIRST 60 MINUTES IN A 6-METER OVEN(4)

Historical Review of Coke-Oven Door Seals

The operators of early by-product coke ovens (prior to 1920) were not concerned with the same types of operating problems as the coke-plant operators of today. From an early publication (1932), the following statement describes the requirements of a good coke-oven door of that time(2):

> "A good coke oven door must close tightly so that no air will enter the oven chambers and damage the quality of coke and gas. It must be a good heat insulator, so as to assure economical operation. The door must also be constructed of such material that its frame will not be attacked by the heat."

The requirements for a good door at that time were similar to those for today's coke plant, except that the early coke-plant operator was concerned with the leakage of air into the ovens, while today's operator although still concerned with leakage into an oven is also concerned with the leakage of steam, gases, and vapors out of the ovens and with the air-pollution problems such leakage creates.

Any discussion pertaining to coke-oven door seals cannot be limited to the seals alone. The coke-oven door, door jamb, seal, and refractory brickwork immediately adjacent to the door jamb all play an important part in maintaining tight coke-oven doors. A coke-oven battery is not a stable structure. The high temperatures occurring in the flues and oven chambers, combined with the periodic exposure of the ovens to atmospheric temperatures during the pushing operations, cause movement throughout the battery. This movement is sufficient to initiate opening of joints in the refractory brick and opening of seals between the refractory brick and door frames. Once the joints have opened and gases can leak from the oven to the door-jamb area, the coke-plant operator's problems increase. The escaping gases can ignite and result in severe damage to doors and door jambs, to the extent that they must be replaced.

Luted Doors

Doors on the first by-product coke ovens were luted to effect the seal between the door and door frame. The earliest of such designs is shown in Figure III-2. The door was a very simple shape with a thin lining of refractory brick. There was considerable distance between the last flue of the ovens and the door, with the result that a considerable amount of uncoked coal (green coke) was produced.

An attempt was made to resolve the green-coke problem by bringing the coke-oven door into the oven so that its inner surface was in line with the end flue as illustrated in Figure III-6.(2) This design may well have been established at the turn of the century. The metal door frame fitted against the refractories, and the final seal was accomplished with luting clay applied between the edge of the door and the adjacent refractory. This type of door did not perform as expected because the short distance between the door and the end flues caused the door to overheat.

Further design changes were made in an attempt to resolve the problem of overheating of the doors. Two of these designs are shown in Figure III-7.(2) In each of these designs, resolution of the overheating problem was attempted by increasing the thickness of the refractory lining in the door. However, in each of these designs the distance between the coke-oven door and end flues was unchanged and there was no improvement in door operation or service life.

Another change in the design of luted coke-oven doors is illustrated in Figure III-8.(2) The metal part of the door frame was moved toward the outside of the oven and the refractory liner took on the shape of the "refractory plug" used on today's coke-oven doors.

Later luted-door designs are illustrated in Figures III-9 and III-10.(5) The door design in Figure III-9 makes use of a roll-formed steel shape to contain the refractories on the ends of the ovens. Structural steel channels are used as buckstays, which is the design retained from the earlier luted doors. Luting clay placed between the metal door frame and the roll-formed steel shape accomplished the seal for controlling leakage. This is one of the earliest designs containing a channel which can be referred to as a "gas passage". The gas passage is a means of exhausting gases from the bottom of the coal charge at the doors to the free space above the coal. Whether this was the intent of designers in that day is not known. In some subsequent illustrations the gas passage is present, while in other examples the gas passage is absent.

The door design illustrated in Figure III-10 shows the same components as the design in Figure III-9, except that the roll-formed steel

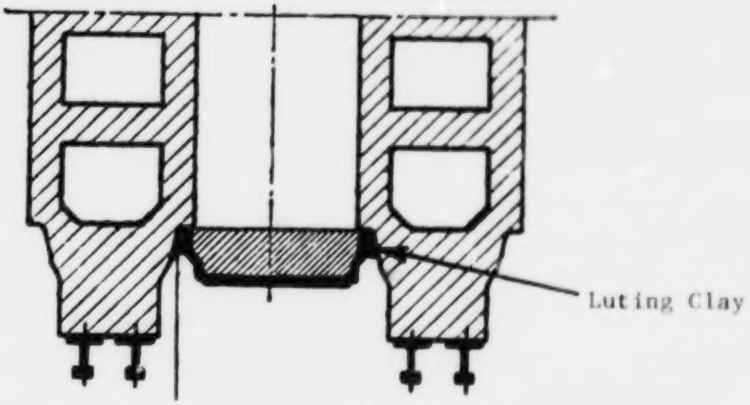

FIGURE III-6. LUTED COKE-OVEN DOOR OF EARLY DESIGN

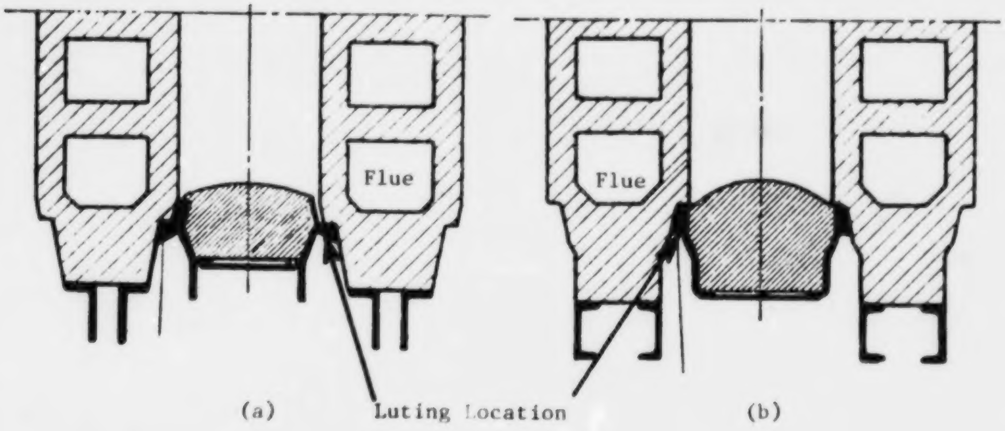

FIGURE III-7. LUTED COKE-OVEN DOORS PRIOR TO 1919

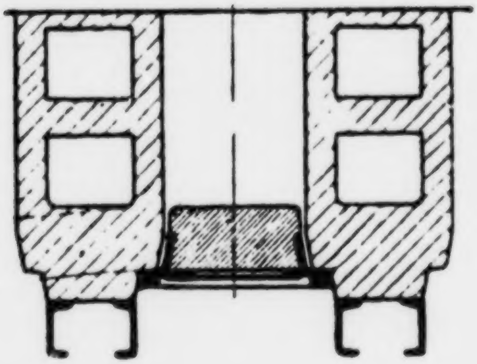

FIGURE III-8. KOPPERS LUTED "STOPPER" DOOR

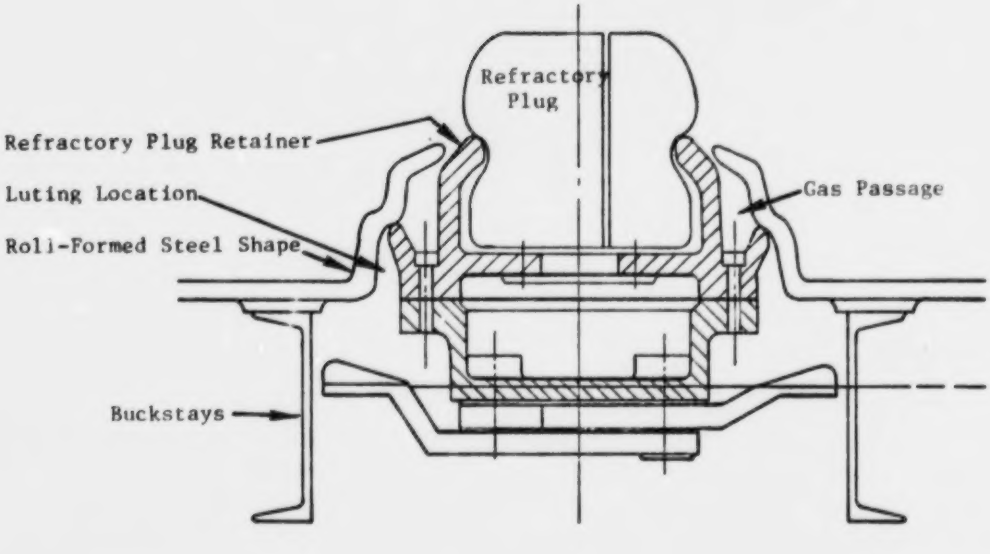

FIGURE III-9. LUTED DOOR DESIGN IN USE ABOUT 1929

section at the end of the refractories has been replaced by a heavy cast structure which also incorporates the door jamb as a distinct component. This is also the first luted door with wide-flange beams as buckstays.

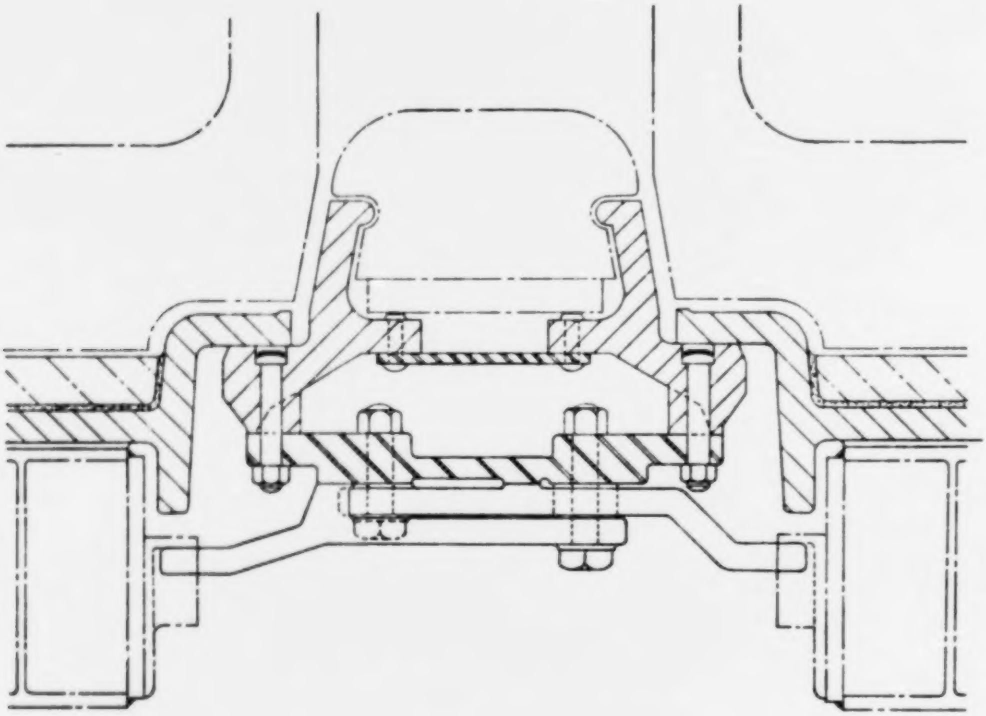

FIGURE III-10. LUTED DOOR DESIGN IN USE ABOUT 1946

Self-Sealing Doors

The first mention of "self-sealing" as applied to coke-oven doors appears to have been in a patent survey published in 1915.(2) The self-sealing coke-oven door was an "Otto" design that is shown in Figure III-11.(2) One of the main features of this design was an integral-frame jamb casting that enclosed the entire end of an oven between the buckstays. This Otto door employed many of the design features that are in use today. The rough adjustment of the door was made by the bolts designated as "5", which are a part of present-day mechanisms. "Fine adjustment" within the various door sections was accomplished by the bolts designated as "11". Quoting from the literature(2):

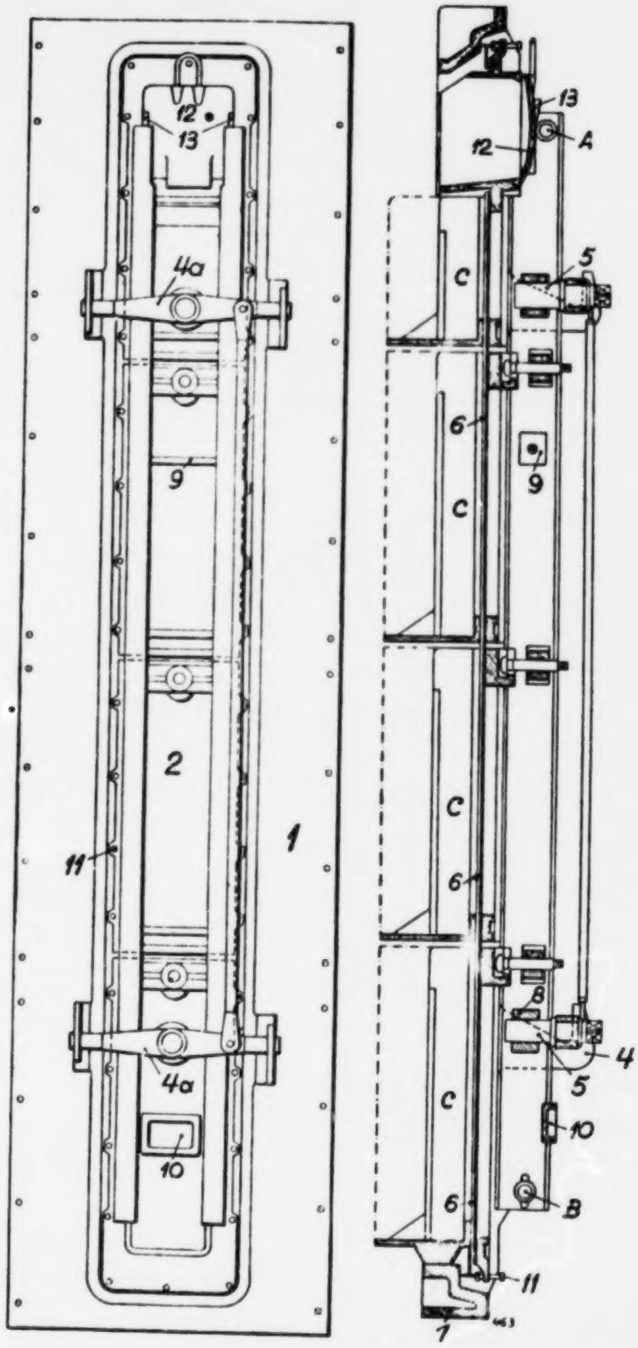

FIGURE III-11. "OTTO" SELF-SEALING DOOR DESIGN, PRIOR TO 1915

> "The door has three links which enable it to bend in an inward as well as in an outward direction. Along the edge of plate "6" there is a flexible rim "7" bearing a sealing frame which consists of a Tee-steel-section."

The use of adjusting bolts, the flexible links, and the sealing frame are design concepts still in use today. The designers of this early self-sealing door had a great deal of confidence in their design as shown from the following statement(2):

> "It is easy to change the sealing frame though this will not be necessary under no circumstances." (This is a correct quote.)

Figures III-12 through III-16 illustrate the various designs of self-sealing doors that have been placed in operation from 1946 through 1970. Figure III-12 is an illustration of a self-sealing door

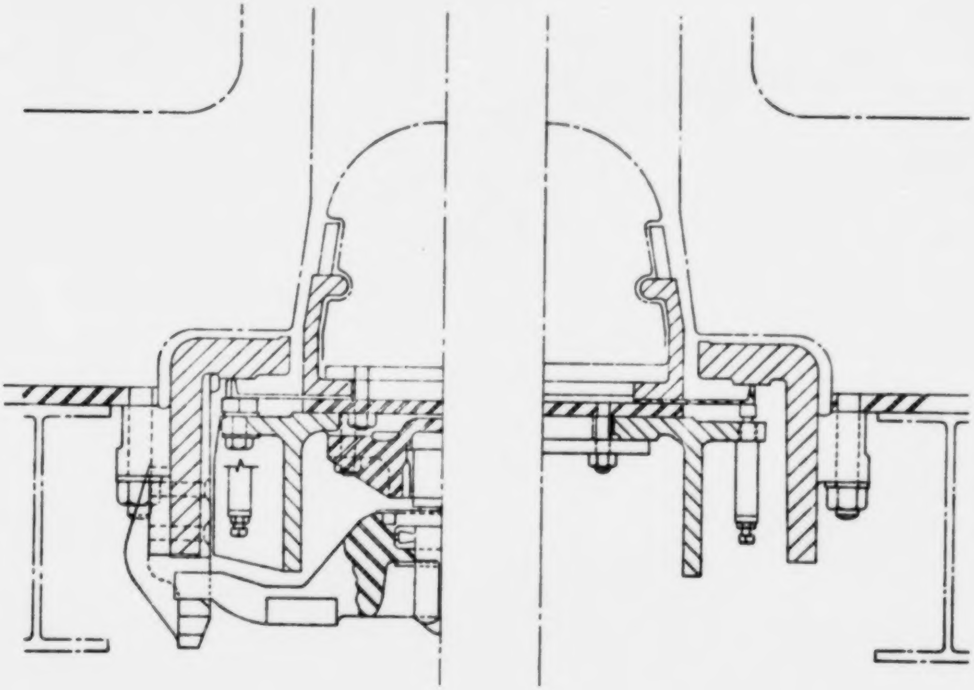

FIGURE III-12. SELF-SEALING DOOR PLACED IN OPERATION IN 1946

for a 4-meter (13-foot) coke oven.[5] The door jamb is removable and is bolted to the buckstay backing plate. The seal component has the cross section of a junior structural channel; the channel web providing flexibility in the seal which is pressed against the jamb by a spring-loaded assembly.

A coke-oven door design for a 4-meter (13-foot) coke oven placed in operation about 1951 is illustrated in Figure III-13. The door has a removable jamb, and a special spring-loaded S-shaped seal. The buckstays for this coke oven are much heavier than those shown in Figure III-12.

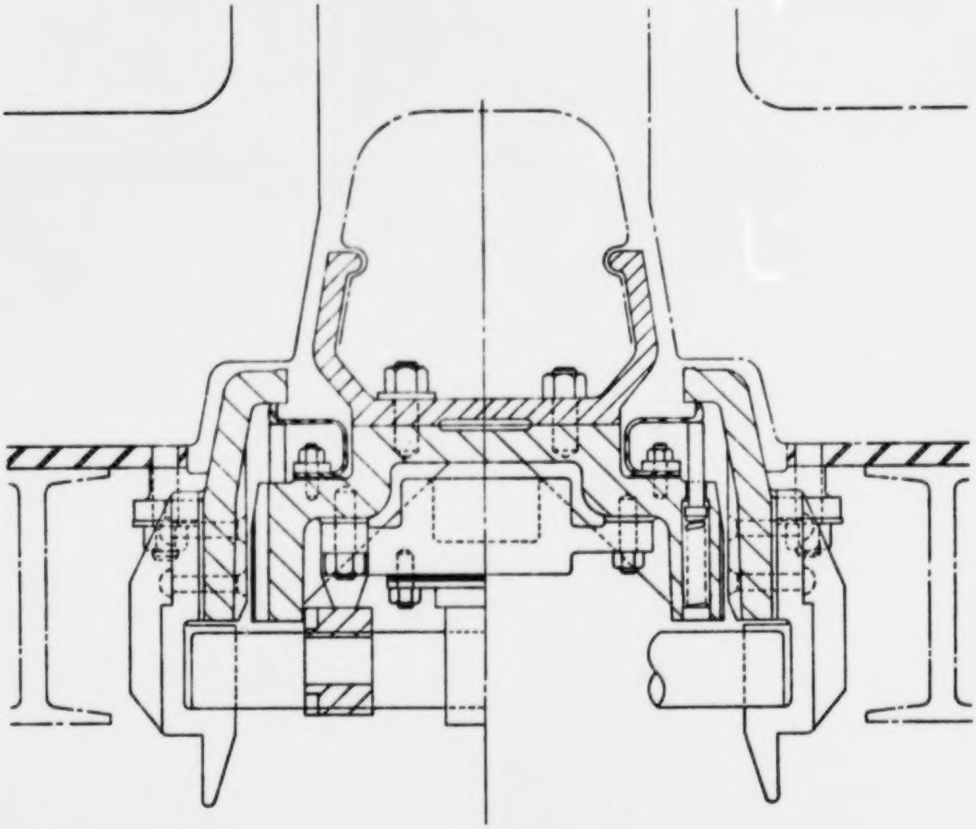

FIGURE III-13. SELF-SEALING DOOR FOR COKE OVEN PLACED IN OPERATION ABOUT 1951

A "turtleback" coke-oven door for a 4-meter (13-foot) battery placed in operation about 1953 is illustrated in Figure III-14.(5) The name "turtleback" comes from the design of the door casting which has a heavy part projecting away from the center of the door. Contrast this design with the doors shown in the preceding figures. A flat sealing ring is used with the adjusting load applied by a bolt passing through the door casting.

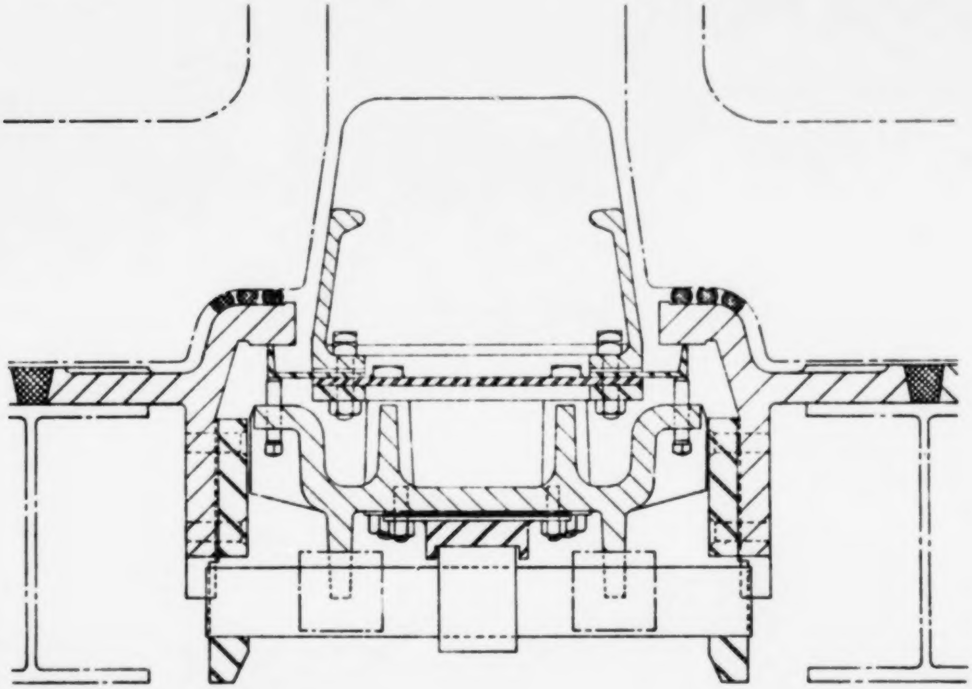

FIGURE III-14. "TURTLEBACK" DOOR FOR A COKE OVEN PLACED IN OPERATION ABOUT 1953

Two coke-oven door designs for ovens placed in operation about 1968 are illustrated in Figures III-15 and III-16. The design shown in Figure III-15 has rolled sections as the main door structure with inserted knife edges in heavier supporting sections for the seal. The knife edge is attached to a flexible diaphragm which also acts as the retainer for the refractory door plug. The knife edge is loaded by bolts passing through lugs welded to the rolled-steel door structure. The door jamb is heavier than in other designs and is held in place by

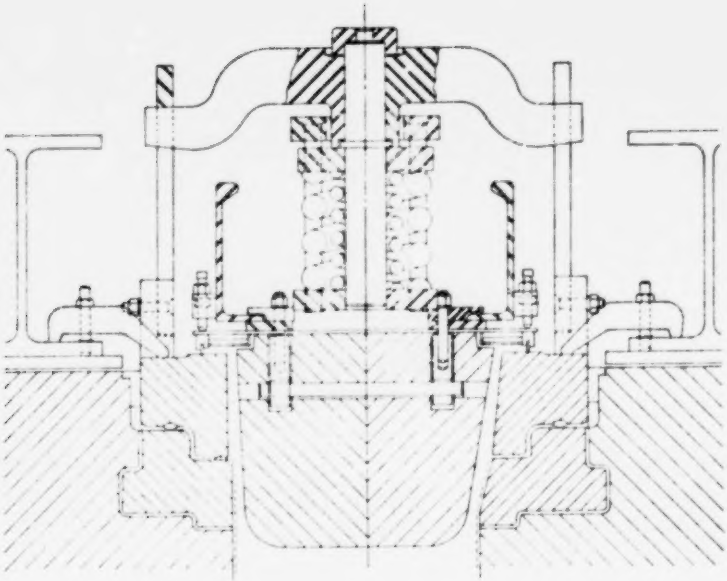

FIGURE III-15. COKE-OVEN DOOR DESIGN FOR 6-METER (20-FOOT) COKE OVEN PLACED IN OPERATION ABOUT 1968

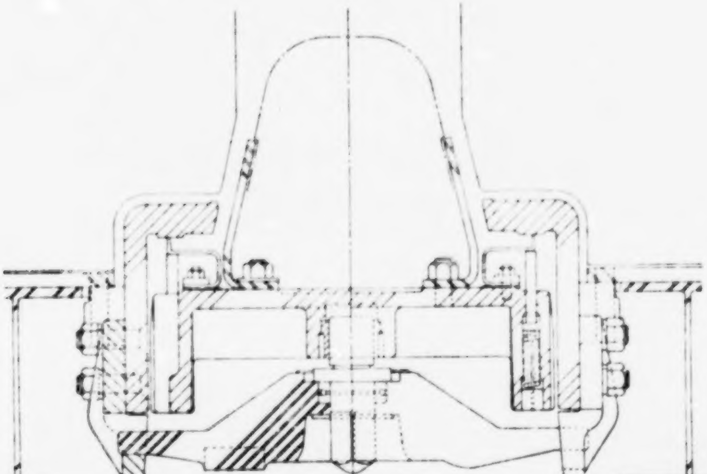

FIGURE III-16. COKE-OVEN DOOR DESIGN FOR A 1968 4.5-METER (15-FOOT) BATTERY

clamps bolted to the buckstays. Figure III-16 illustrates another door from a 4.5-meter (15-foot) battery placed in operation during 1968. The coke-oven door jamb is bolted to the buckstay backing plate permitting removal and replacement. Spring-loaded pins are used to load the S-shaped seal.

Knife-Edge Designs

Some knife-edge designs are evident in the figures in the preceding section. Several other designs are illustrated in Figure III-17.(6)

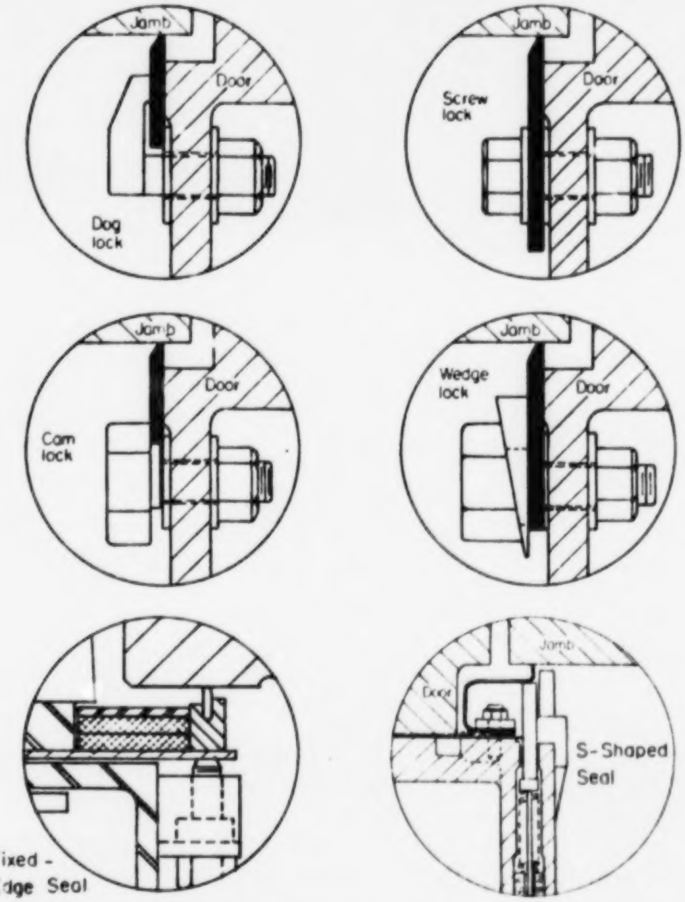

FIGURE III-17. KNIFE-EDGE SEAL DESIGNS FOR COKE-OVEN DOORS

The two bottom designs shown are predominant in the vast majority of coke ovens in the United States. These are often described in terms of the name of the builder and also in descriptive terms. For the purposes of this report, Battelle terms the bottom-left design as the "fixed-edge design" and the bottom-right design as the "S-shaped seal design".

Although the exact reasoning behind the designs has not been stated, the thought is generally expressed that a narrow edge on the sealing surface would cut into a tar deposit on the door jamb and provide improved sealing. Another line of reasoning suggests that the knife edge offers a small area (total area of the thin knife edge) to make leak-tight and, therefore, lowers the force needed to make a good seal.

Coke-Oven Door Design Developments

In the past 2 years considerable work has been done on two developments. One is the use of vented refractory plugs in the coke-oven doors and the other is the use of water-cooled door jambs on the coke ovens. However, the basic ideas of these developments were patented before 1932.(2)

Vented Refractory Door Plugs

Patents were issued before 1932 for doors with flues. German Patent Number 86, 145 was issued to Dr. Otto and Company, German Patent Number 97, 480 to J. W. Neinhans, and U. S. Patent Number 100, 774 to F. Wolff for coke-oven doors with flues. The patents described the flues as a means of introducing heat to the door plug for the purpose of lowering heat losses from the oven chamber through the door. The vents were not identified as useful to carry gases from the bottom of the coke oven to the free space above the coal.

In 1953, the idea was reported of venting coke-oven door plugs as a means for conveying the gases and vapors formed at the bottom of coke ovens to the free space of the oven. The concept was patented by Friederick Goldschmidt and became known as the "Goldschmidt Door", which is illustrated in Figure III-18.(7) A year later, 12 coke plants were reported to be operating in the United Kingdom with the vented

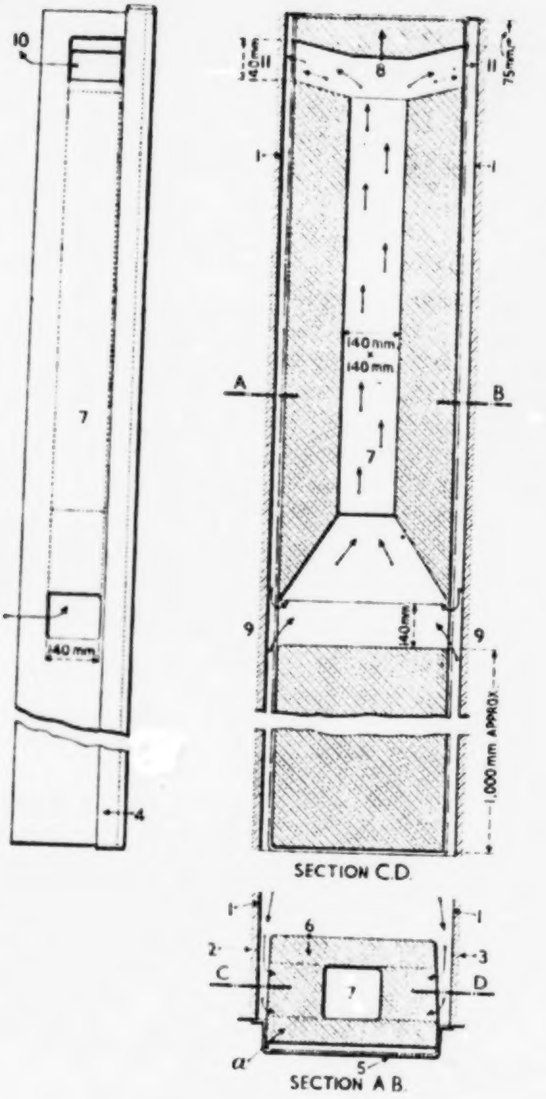

FIGURE III-18. THE GOLDSCHMIDT VENTED COKE-OVEN DOOR(7)

door plugs.(8) The following statements were reported with reference to the operating situation:

> "The heavy gassing and leakage, so often noticeable when an oven is first charged are absent. So also is the egress of heavy tarry matter and pitch, generally noticeable around the leveler door and the bottom of the door seal."
>
> "The work of cleaning and scraping the self-sealing doors was reduced to a minimum and in some cases did not appear to be necessary."
>
> "There was complete absence of leakage from the Goldschmidt door both when the ovens were first charged and throughout the coking time."(8)

However, the preceding quotes must be qualified by the fact that no published reports concerning the Goldschmidt door appeared in subsequent years to verify the claims.

The vents in the refractory plug of the coke-oven door provide an easy passage for the crude gas from the bottom of the ovens at the doors to the free space above the coal, thereby lowering the pressure at the coke-oven door seal. The vented plug has received renewed attention by coke-plant operators in the United States as evidenced by two papers delivered at the April, 1974, AIME Ironmaking Conference.(9, 10) Work is continuing at several coke-oven plants throughout the country to develop the design concepts for efficient use of vented coke-oven door plugs.

Water-Cooled Door Jambs

U.S. Patent Number 725,471 was issued to E. A. Moore before 1932. No further information was found pertaining to the possible application of this concept. During the course of field visits and field trials for this study, the application of water-cooled jambs was observed at a coke-oven battery. Details of these studies are discussed elsewhere in this report (Chapter IV).

Most Recent Coke-Oven-Door Design Concept

The most recent design concept up to the time of the writing of this report is being used on a 5-meter (16.4-foot) coke-oven battery under construction during 1974 in Canada. The design is illustrated in Figure III-19.(11) The following elements are used: (1) heavy buckstays, (2) heavy buckstay backing plates, (3) heavy door jambs bolted to the backing plate for ease of door-jamb removal, (4) specially designed refractory shapes to minimize paths for gas leakage to the doors and jambs, (5) blanket woven refractories placed in critical refractory-shape joints to permit movement of refractories and still restrict the passage of gases, (6) flexible door diaphragm, (7) knife-edge seals, and (8) a vented refractory door plug.

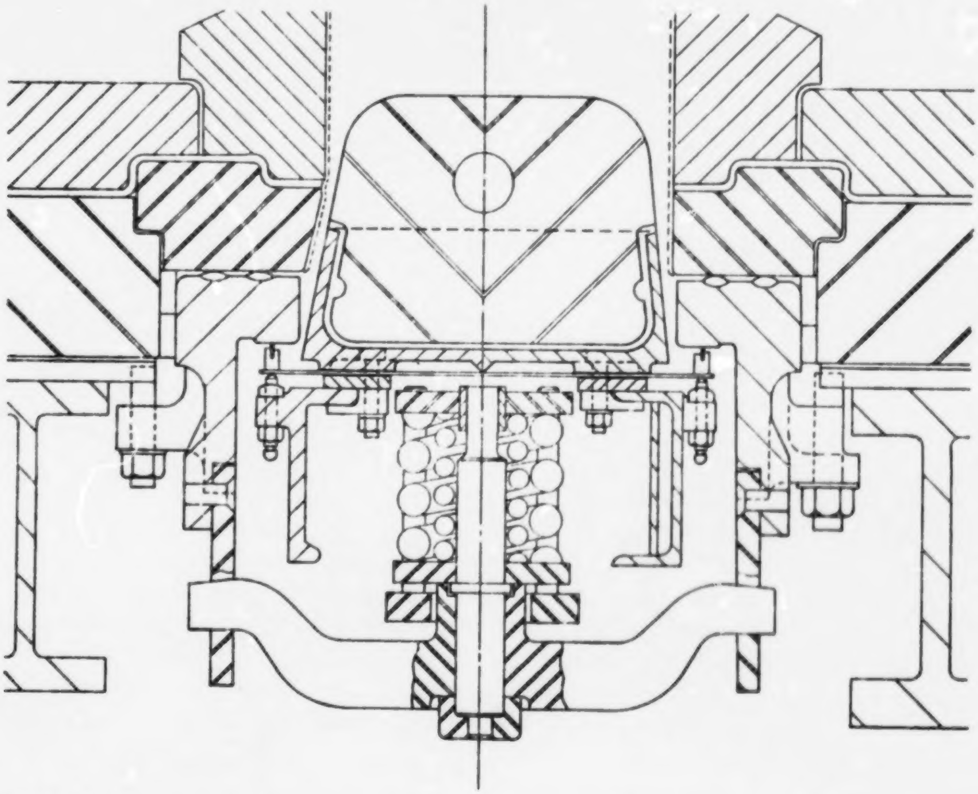

FIGURE III-19. RECENT COKE-OVEN-DOOR DESIGN USED ON A BATTERY UNDER CONSTRUCTION DURING 1974

References for Chapter III

(1) Sheridan, E. T., and DeCarlo, J. A., "Coal Carbonization in the United States, 1900-62", U. S. Bureau of Mines Information Circular 5251, U. S. Department of the Interior, p. 4 (1965).

(2) Gluud, W., and Jacobson, D. L., "International Handbook of the By-Product Coke Industry", The Chemical Catalog Company, Inc., New York, New York, pp. 346-360 (1932).

(3) Brown, W. T., "By-Product Oven Operation Under Present Conditions, Part II", Blast Furnace and Steel Plant, 30 (2), pp. 219-223 (February, 1942).

(4) Muller, J. M., "Gary Coke-Oven Door Development Program", Paper presented at the Joint Meeting of the Eastern and Western States Blast Furnace and Coke Oven Association, 43 pp. (October 25, 1974).

(5) Voelker, F. C., Koppers Company, Inc., communication to John Varga, Jr., Battelle's Columbus Laboratories (September 9, 1974).

(6) Barnes, T. M., Hoffman, A. O., and Lownie, Jr., H. W., "Evaluation of Process Alternatives to Improve Control of Air Pollution from Production of Coke", PB No. 189266, National Air Pollution Control Administration, Department of Health, Education, and Welfare, 166 pp. (January 31, 1970).

(7) Cellan-Jones, G., "A New Self-Sealing Coke-Oven Door", Coke and Gas, 15, pp. 221-222 (June, 1953).

(8) Cellan-Jones, G., "The Goldschmidt Door", Coke and Gas, 16, pp. 307-310 (August, 1954).

(9) Komac, T., "Vent Door Linings - Do They Work?", AIME Ironmaking Proceedings, 33, pp. 391-396 (1974).

(10) Cameron, A. M., "Factors to be Considered When Designing a Coke-Oven Door", AIME Proceedings, 33, pp. 397-399 (1974).

(11) Cameron, A. J., Communication to R. Paul, Battelle's Columbus Laboratories (November 1, 1974).

CHAPTER IV

INVESTIGATION AND DISCUSSION OF THE CAUSES OF THE EMISSIONS PROBLEM

This chapter deals with the tests and judgments made by Battelle researchers in their efforts to "define the problem". Also included are sections "Technical Specifications That New Sealing Systems Should Meet" and "Judgments and Opinions On Existing End-Closure Sealing Systems".

Introduction and General Statement of the Problem

Overall, "the" problem to be solved is that almost all coke-oven doors release hydrocarbon emissions (smoke and volatiles) into the atmosphere during the early part of the coking cycle and even during the entire coking cycle. Equipment which may seal reasonably well when new degrades because of the rough and severe service conditions so that leakage becomes worse as the equipment and machinery become older. The personnel in the coke-producing industry (management and labor), EPA, and other organizations concerned with worker health want this leakage problem eliminated in existing and future coke batteries. In the present research, "emissions" are judged primarily as the presence of visible emissions.

The complexity of the problem is a function of many factors that are dealt with in this chapter. However, an overall conclusion in this research program is that door leakage cannot be eliminated consistently only by overhauling the present end-closure components or by increasing the overall maintenance effort on present designs.

Technical personnel from coke-producing companies, who have assignments to eliminate the emission problem, have often made statements such as "We have just completed an overhaul of all of the sealing and latching mechanisms, and emissions were lowered. However, as you can see the emission rate is already climbing".

This inability to hold an effective seal for a reasonable length of time was confirmed at a plant where Battelle researchers were monitoring a test door. A rebuilt door was placed on a coke oven and the new seal eliminated visible emissions for the period of the test (1 week). However, upon revisiting the test door 11 weeks later, it was found that this door was leaking significantly without any evidence of damage to the seal. There was, however, evidence of thermal warpage of the seal in the area of leakage.

It was not a part of Battelle's scope of work on this program to develop a quantitative method for evaluating the range of door-leakage emissions in the coke-producing industry. However, one assigned task was to develop a method for evaluating the leakage from future test doors or from future doors incorporating new sealing concepts. This work is reported later in Chapter VIII.

The overall degree of door leakage varies considerably from one coke battery to another. There is a variability depending on battery age, type of seal design, and the past and present level of repair and replacement. There is little agreement between observers on quantity designations for door emissions. However, for purposes of illustration of the problem of visible emissions, Figures IV-1 and IV-2 are examples of visible leakage from a single door and heavy visible emissions from doors in an entire battery.

Summary and Conclusions

The research, experiments, tests, and observations on which this section is based are described later in the chapter. However, to orient the reader early to the conclusions resulting from the data that were collected, the results are summarized here before the details and data are presented.

(1) By its very nature, a coke-oven battery is not a dimensionally stable structure. It is reasoned, but not proven, that there

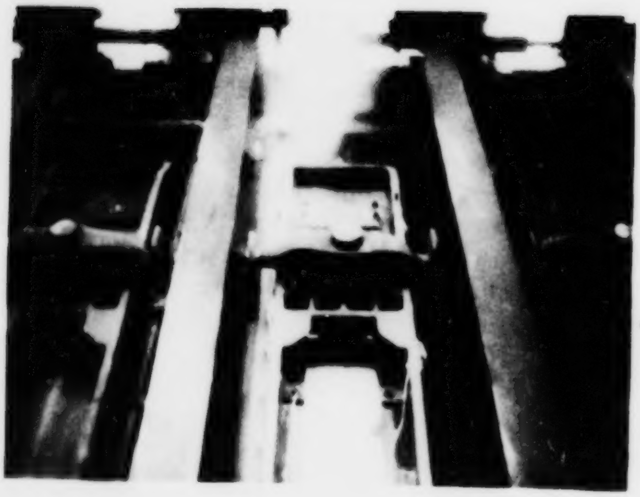

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FIGURE IV-1. PHOTOGRAPH OF LEAKAGE OF EMISSIONS FROM A SINGLE DOOR

(Photographed from bottom of doors – doors are vertical.)

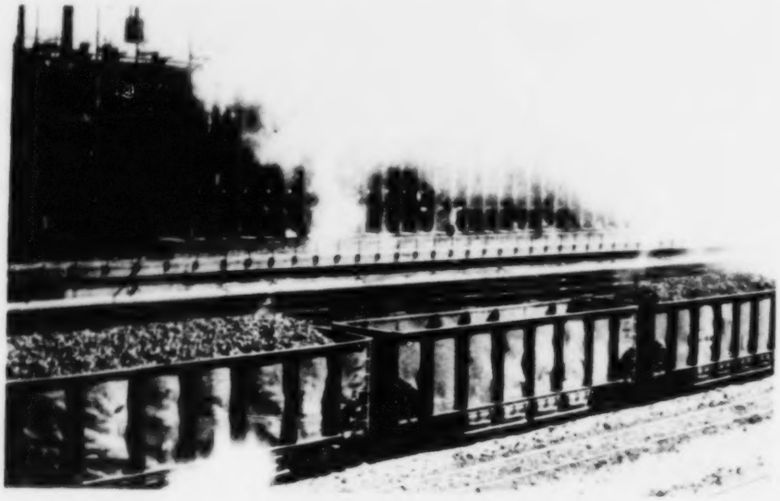

FIGURE IV-2. PHOTOGRAPH OF HEAVY EMISSION FROM DOORS IN A COKE-OVEN BATTERY

is some thermal deflection of battery trim and end-closure components (jamb/seal/door) on every coking cycle.

(2) There is evidence of thermal warpage of most metal components at the ends of coke ovens. This warpage is caused by thermal cycling, under constrained conditions, coupled with warpage due to occasional temperature excursions*. Battelle has no direct evidence - such as thermocouple records - illustrating temperature excursions, but has collected evidence of internal oxidation of cast iron jambs at the top of the ovens. This oxidation, which leads to growth in the volume of cast iron, indicates that the gray iron castings in these locations have been repetitively heated above 425 C (about 800 F). "Normal" jamb temperature readings in this location are about 260 C (about 500 F).

(3) In measuring jambs, it is evident that there is severe thermal warping, and there also is some evidence of thermal buckling of the door-mounted seal edges of the S-shaped seal design. Presumably, such seals had been subjected to a temperature excursion.*

The major problems, however, are the bowing of the jambs and the inability of the various designs of seal-edge arrangements to accommodate themselves to jamb distortion, particularly inward jamb distortion. The bowing of jambs is the inward and outward displacement of the jamb's seal-mating surface relative to a reference line drawn from the top to the bottom of a jamb. The data included in this chapter indicate a possible maximum inward displacement of 17.5 mm (0.7 inch) over a span of 2.4 m (8 feet) and a maximum outward displacement of 8 mm (0.28 inch) over a span of 2.4 m (8 feet). There are no data available indicating the range of jamb bowing throughout the coke-producing industry. It is believed, however, that almost all jambs have been distorted to some degree.

(4) Because the vast majority of coke batteries in the United States are of the Koppers and Wilputte design, the retrofitability consideration that is basic to this program is mainly concerned with coke batteries (specifically the end-closure components) of these two designs. Because these end-closures differ in design, each is treated and discussed separately. The major concern in this comparison is the ability of the designs to accommodate to warped jambs. In this regard, it should be appreciated that

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*"Temperature excursions" are periods during which the temperature of the part exceeds the normal and usual operating temperature by a large amount. A temperature excursion is a temporary condition which may be of short or long duration.

neither design was built to accommodate the degree of warpage that now exists on most operating coke ovens. Each design has flaws and strong points, some of which are discussed later.

Relative to the fixed-edge seal (see page III-16), the S-shaped seal is a more flexible design inasmuch as it can automatically accommodate itself to outward bowing of the jamb, and to continued outward bowing of the jamb with time. Required inward deflection of the seal (to enter an inward bow on the jamb), on the other hand, is supposed to be accomplished by the combination action of (a) the backward deflection of the entire seal when mounting the door, and (b) the counteracting inward force of the spring-loaded plungers pressing against the back of the sealing edge. The required inward deflecting forces now provided against the seal are insufficient to accommodate a deep valley or a narrow-pitch, wide-amplitude inward displacement of a jamb.

A complicating factor in this judgment is that S-shaped seals in operation are under high compressive strain because the thermal expansion of the hot seal is restrained by the numerous mounting bolts. Whereas the S-seal in an ambient-temperature test stand will deflect outward easily, it has been noted that many S-shaped seals in operation splay sideways between the two latching mechanisms. That is, they elect to splay to the side plus deflection backwards. Specific answers in this regard can be obtained only after completing a stress analysis (strain-gauge) program.

The fixed-edge seal design consists of a sealing-edge mounted inboard on a relatively inflexible beam or seal-edge holder. This assembly is set into accommodation to the jamb shape by manual tightening or loosening of bolts pressing against the back of the seal assembly. The stiffness of the seal-edge holder makes it improbable that this type of seal can accommodate extreme instances of inward and outward bowing on jambs. In theory, the deflection bolts should require only occasional adjustment. However, bolt adjustment is a difficult and artful operation. In addition, the seal-deflection bolts become loose with time.

(5) Visible emissions from coke-oven doors are almost always the result of a gap between the seal edge and the deposits on the jamb (or the jamb surface itself). Minor physical damage to the seals (bends and dents) were observed; but, for the purposes of this summary, visible emissions are caused by open spaces

between the seal edge and the jamb. Gaps are the result of many conditions, some of which are as follows:

- Excessive inward jamb displacement or bowing which the seal cannot accommodate.
- Removal of jamb deposits which formerly sealed a gap (filler material removed).
- Uneven or low sealing force on the door during the mounting procedure. (This problem has been described in a recent paper*.)
- Warpage of the seal edge because of thermal buckling. The formation of this gap is usually accompanied by a backward deflection of the entire sealing edge above the upper latch.
- Hourglassing** of the jamb to the point where part of the seal edge does not strike the jamb surface.
- Placement of a fixed-edge seal off the spot; i.e., either left or right of the original adjustment spot, meaning that the seal can be against a different configuration of the jamb.
- Accumulation of hardened deposits in the door gas passage to the point where the seal is physically backed off of the jamb.
- Accumulation of the corners of the jamb of hardened deposits that prevent the stop bolts from touching the jamb itself.

(6) Any gap between the seal and the jamb (or jamb plus deposits) will, early in the cycle, release visible emissions of combined low-boiling-point hydrocarbons and uncondensed steam. This mixture will not "self-seal" gaps.

Later in the cycle when the steam volume has decreased and the hydrocarbons and tars start to condense on the jamb, gaps will close in stages, starting generally from the bottom of the door. The temperature of jambs increases from the bottom to the top of the jamb and, therefore, "sealing" (condensing) tars arrive at the bottom gaps before they plug off the top gaps. In many instances observed, the top gaps never seal.

(7) Cleaning of the jambs is important only if the deposits become hard. It is believed that jamb deposits become hard only slowly at "normal" jamb temperatures. It is known, however, that

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*Muller, J. M., "Gary Coke-Oven Door Development Program", Paper Presented at the Joint Meeting of the Eastern and Western States Blast Furnace and Coke Oven Association, October 25, 1974. This paper can be obtained by writing to the United States Steel Corporation, 600 Grant Street, Pittsburgh, Pa. 15230.

**Hourglassing is the distortion of a jamb such that the distance between the two sides is less in the center of the jamb than at the ends of the jamb.

heating of coal-tar pitch to 340 C (650 F) will result in rapid exothermic (heat releasing) reactions that emit gaseous hydrocarbons from the tar and leave behind an adhering form of hard carbon. It is indicated, but not proven, that thermal excursions can be the cause of hard deposits on jambs.

(8) It was judged that new sealing systems should meet the following technical specifications:
   - Must withstand 200 to 315 C (400 to 600 F) for prolonged periods without deterioration.
   - Must withstand occasional short temperature excursions to 430 C (800 F), without being destroyed.
   - Should automatically seal gaps, i. e., no manual adjustment required when placing any door on any oven on one side of a battery.
   - Must have increased gap-closure capability – up to four to five times that of the flexible S-shape seal now in operation.
   - Must withstand corrosion and chemical attack of hot gases and liquids.
   - Must be total-failure proof, i. e., not susceptible to the possibility of complete failure during any cycle.
   - Must not present new and insolvable cleaning problems.

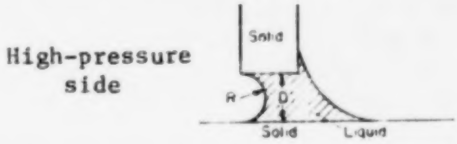
(9) Very little information is available on various basic measurements and parameters within the coke-producing industry. Because of lack of data (and subsequent analysis), there is a wide range of opinions within the industry. Within the funding of this particular task, Battelle researchers could not examine any facet of the basic problem in depth. However, the effort expended in this task approached the problem at its core.

Fundamentals of Demountable Industrial Seals

In many batch-type industrial applications, there is a need for demountable seals on doors and covers that are closed and opened as required. Coke-oven doors are one example of a large, demountable-sealing application that has particular problems.

Sealing in any application is accomplished by achieving and maintaining a continuous barrier (fluid or solid) against the transfer of materials between the seal element and the mating coupling surfaces.* With existing coke-door sealing designs, the problems are both in achieving and in the maintaining of a continuous barrier.

Some coke-plant operators are of the opinion that surface tension plays a role in the sealing of existing coke-oven doors. An example of this type of seal is shown in the following sketch.



In this type of seal the two solids are wet by a liquid and the liquid will remain in place (seals) if the differential pressure is low and the gap is small, and if the surface tension of the liquid is high. The equation for calculating the workable gap distance is as follows**:

> $D = 2\delta/P_1$, where D is the gap in centimeters, δ is the surface tension of the liquid sealing material in dyne/cm, and P_1 is the differential pressure in dyne/cm^2. (1 atmosphere = 1×10^6 dyne/cm^2.)

If the organic liquids that condense at the metal seals of standard coke-oven doors have a surface tension of about 30 dyne/cm, then the calculated gaps that these liquids would seal (by surface-tension effects) are as follows:

Differential Pressure Across the Gap	Calculated Gap Sealed by Organic Liquids
100 mm H_2O (4 inches)	0.006 cm (0.002 inch)
700 mm H_2O (1 psi)	0.0009 cm (0.0003 inch)

Although Battelle researchers have been told by coke-plant operators that gaps of 0.006 cm (0.002 inch) should not leak, the researchers doubt that surface-tension effects do much sealing at coke-oven doors, at least during the initial period of high pressure at the door seals. As described later in the test-results portion of this chapter, the initial 100 mm H_2O pressure developed in some 3.65-meter (13-foot) coke ovens is by volume more than 50 percent uncondensed steam. The calculations for 700 mm H_2O internal pressure were included in the foregoing listing because it is being reported that 6-meter ovens encounter this high pressure at the start of the coking cycle.

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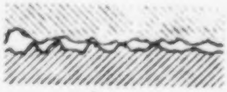
*Daniels, C. M., "Aerospace Cryogenic Static Seals", Journal of the American Society for Lubrication Engineers, April, 1973, p. 157.

**Roth, A., Vacuum Sealing Techniques, Pergamon Press, 1966.

Most coke-door seals depend on pressing a door-mounted edge strip against the mating face on the oven-mounted jamb (door frame). These are described as being "self-sealing" seals. This designation is used because most areas of leakage on door seals eventually stop leaking after some variable period of time. This may be due to a surface-tension effect when high-boiling-temperature liquids condense at the seals, but Battelle's field tests indicate that visible emissions from doors stop after (a) the internal pressure at the door has dropped and (b) condensed and partially solidified tars build up on the jamb in front of the leak and block off the emission flow.*

The light pressure of the door-mounted edge strip against the mating face on the oven-mounted jamb does not present a solid barrier to the leakage of vapors and gases, Without metal deformation, metal-to-metal contact represents only a contacting of the high points on the two surfaces as illustrated below in the schematic cross section through a metal-to-metal joint without a gasket.



To a gas or a vapor, the valleys between the contacting high points are an escape route. The rate of leakage between the two mating surfaces is partially a function of the surface finish of these surfaces. However, testing at Battelle, simulating coke-oven seal conditions of temperature and mating pressures has shown that there is gas leakage between clean, undeformed metal contact surfaces at all levels of practical industrial finishes.

To develop a true, demountable, static seal it is necessary to fill the roughness of the mating surfaces. This filling operation can be accomplished with (a) compressible (one-use) gaskets; (b) resilient, compressible materials (rubber and elastomer materials); and (c) compression of relatively plastic coatings on either one or both of the metal mating surfaces. A sketch showing the "filler" action of gaskets and compressible materials is shown below in the schematic cross section through a metal-to-metal joint with filler material.

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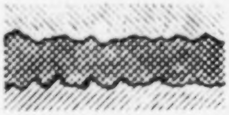
*See the Field-Test Results later in this chapter.



Battelle researchers have seen new metallic sealing strips contacting old jamb surfaces without the release of any visible emissions on any portion of the coking cycle. In this instance, the deformable or filler material between the mating metallic surfaces was the coating of hot, soft tars remaining on the jamb surface from previous coking cycles. This filler effect is in operation even when the jamb has been carefully scraped to what would appear to be a clean metal surface. The filler in this instance is a thin residual film of tar on the jamb. Instances have also been observed where a thick layer of material on the jamb was able to seal a relatively large gap between the sealing edge and the jamb when the seal touched and/or compressed the jamb deposit.

In summary, effective demountable seals need a barrier between the two mating surfaces to prevent leakage. In coke-oven doors that are leak-free from the start of the cycle, the barrier is residual tars on the jamb. If, however, there is between the sealing edge and the jamb a gap that is not filled with tar, the gap will leak heavily until later in the cycle when heavy tarry materials condense on the jamb and plug or dam the leak.

It is apparent that with improvements in the metal-to-metal concepts for sealing coke-oven doors, there will still be a need for a compressible or pliable material on the door jamb. If steps are taken to eliminate the deposition of tars on the jambs, then steps will have to be taken to develop a suitable substitute material.

Laboratory-Test Results

Examination of a Discarded Jamb

As indicated by measurements taken in the field-test program, (page IV-34), cast jambs made of gray iron bow, hourglass, and probably twist. Bowing is the inward and outward distortion of the jamb from a reference line between the top and bottom of the jamb. Hourglassing is the tendency for the jamb opening to become smaller at the middle of the jamb as referenced to the ends.

During the course of this program, a coke-producing company shipped a discarded coke-side jamb to Battelle for examination. The first saw cut into the discarded jamb was at the coal line on the side piece of the jamb sprang inward a distance of about 38 mm (about 1-1/2 inches). This indicated that the as-received jamb was under considerable residual stress (in the direction of hourglassing). If it is assumed that this particular jamb was stress relieved following manufacture, or was stress relieved in service, then the residual stresses noted were the result of nonuniform plastic deformation during use.

Complete cross sections of the jamb were removed for metallographic examination. These sections were from the center of the top member (top of jamb), and from the top, middle, and bottom of one side member.

Brinell hardness numbers (BHN) were determined for various positions on the sections. The hardness values were in the range of 155 to 170 BHN for all areas in the side sections except in the seal-mating surface location on the top section. This area had apparently been overheated in service with a resultant lowering of the hardness from 160 to 120 BHN. The entire section from the top member was softened down to a level of 110 to 134 BHN. These hardness readings lead to the conclusion that the softer areas were annealed while in service. At temperatures of 600 C (1100 F) or lower, such softening as occurred requires a total of weeks of exposure to such temperatures.

Samples for metallographic specimens taken from the four sections were polished and etched for examination under a microscope at magnifications ranging from 100 to 500 diameters. From each section, samples were taken from the inside edge of the jamb (the portion directly facing the door plug and parallel with the oven bricks and called the "hot face") and from the outboard end of the jamb wing. All of the specimens taken from the sections at the bottom and the middle of the jamb were typical gray iron (flake graphite in a matrix of pearlite). This structure was probably quite similar to the microstructure of the entire jamb before it was placed into service.

The microstructure of the hot-face location from the top of the side member, as shown in Figure IV-3, showed that the metal in that area had been subjected to cyclic heating to temperatures that could cause "growth". Structural evidence of this condition is the network of oxide particles around the graphite flakes, partial replacement of the graphite with iron oxide, and the decarburization of the matrix as indicated by the lower amount of pearlite.

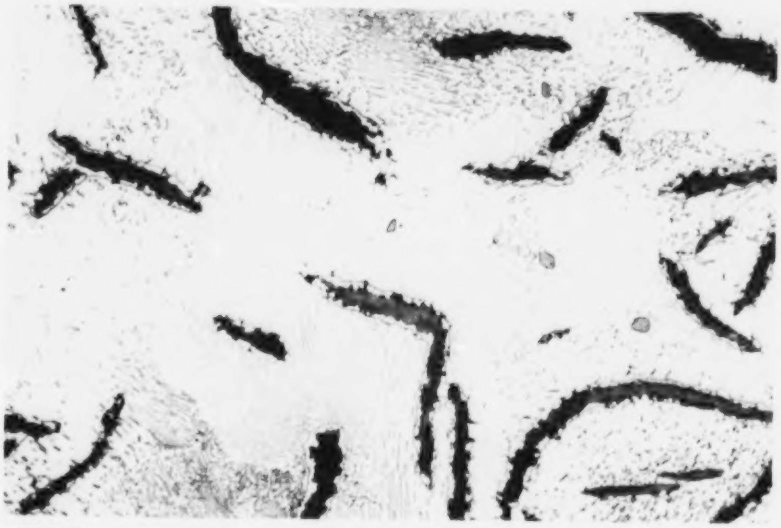
The microstructure of the hot face of the top cross piece shows that the metal in that area had experienced severe growth of a degree that can occur in unalloyed gray iron only at high temperatures over an extended period of time. Figure IV-4 shows that the graphite had been almost entirely replaced with iron oxide and that considerable internal oxidation had occurred throughout the matrix. Also, there was virtually no carbide phase (pearlite) remaining in the matrix. This structural condition extended through most of the section.

This metallographic study established that the upper part of the door jamb, and particularly the portion of the jamb near and where the door seals, was severely affected by the mechanism that is commonly referred to as "growth".

Growth in cast iron is a nonreversible increase in volume that results from microstructural changes such as occur from the cyclic heating of the cast iron to elevated temperatures. There is a significant increase in growth rate if the temperature extends above the range in which the transformation reactions occur. This range is 700 C and higher (about 1300 F and higher). The start of internal oxidation leading to growth is at a temperature of about 425 C (about 800 F). Growth is further accelerated by strong oxidizing conditions or by the presence of sulfur-bearing gas in the environment. When this nonreversible increase in volume occurs, it is inevitable that the parts will develop internal stresses, warp, and ultimately become unfit for service.

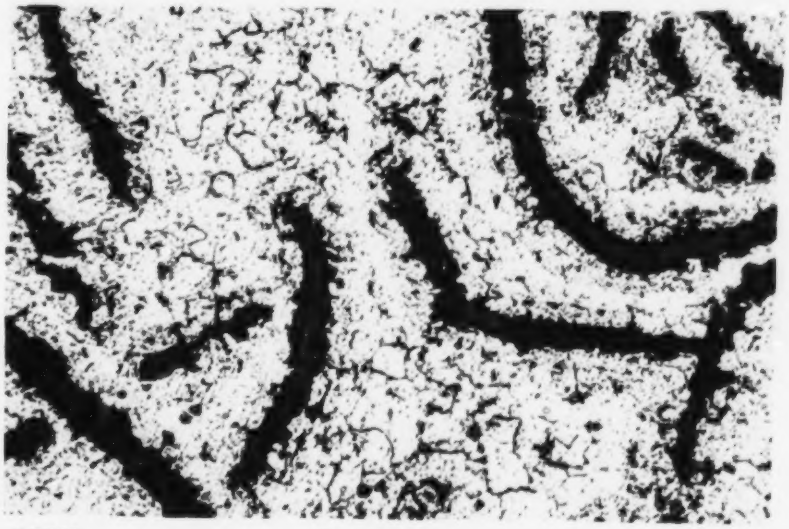
Three conclusions were drawn from the work on this discarded jamb:

(1) The top portion of this jamb (and possibly many more jambs in service) was heated numerous times above 425 C (800 F) and may have been cycled to higher temperatures for appreciable periods of time.



500X Picral Etch

FIGURE IV-3. MICROSTRUCTURE OF A METAL SAMPLE TAKEN FROM NEAR THE TOP OF THE SIDE MEMBER OF A DISCARDED JAMB, CLOSE TO THE SEAL CONTACT AREA



500X Picral Etch

FIGURE IV-4. MICROSTRUCTURE OF A METAL SAMPLE TAKEN FROM THE CENTER OF THE TOP MEMBER OF THE DISCARDED DOOR JAMB

(2) A metal other than unalloyed gray iron should be considered the coke-oven jambs.

(3) Temperature excursions can and do occur at least to some coke-oven jambs and door seals.

Temperature data summarized in a following portion of this chapter show that the highest jamb temperatures measured by Battelle researchers were about 340 C (650 F). Although these temperatures were taken on the end of the seal edges, subsequent sampling with a contact thermocouple did not show any top-jamb temperatures over 260 C (500 F).

It was concluded that all of the temperatures taken by Battelle were outside of the periods when high-temperature excursions occur on coke-oven jambs and door seals. It is not known for sure when these temperature excursions occur, but they probably occur during periods when doors are kept on empty ovens for prolonged periods of time. These periods can occur when the charging machine malfunctions and the ovens are pushed "ahead"; i. e., ovens are pushed empty ahead of the charging machine in a plan that the charging machine will (and does) eventually catch up, i. e., no production tonnage is lost. Another possible factor is prolonged decarbonization of ovens to remove roof carbon, either with or without coke in the oven.

It is believed that temperature excursions play a major role in warping coke-oven jambs and also, in some instances, coke-oven seal edges. With a door on an empty oven, the entire length of the gas-passage area* and the general seal-edge area and jamb are subjected to direct and reflected radiant heat over the entire height of the door. The level of thermal stresses developed during these temperature excursions can be high and damaging. A disturbing consideration is that jambs and edge seals may be overstressed during the period a coke-oven battery is first put on line. That is, the initial heating of new equipment (with no coal in the ovens) may cause the initial warpage. Once distortion has started, it becomes easier to continue the distortion.

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*The gas-passage area is a channel on the door side of a seal strip.

Laboratory Metal-to-Metal Sealing Results

At the start of this program there was some question from the supervisors of host coke plants and from the Battelle researchers as to "What is the mechanism of sealing at coke-oven doors"? The decision was made to attempt to answer this question in both field trips and in laboratory experiments.

For the laboratory tests, a miniature coke-oven seal (with a full-size seal edge) was made using a circular seal pressed against a steel block as shown in Figures IV-5 and IV-6.

It was arranged that this test rig could be heated to the reported coke-oven jamb temperature of 260 C (500 F) and could be given the same calculated average mating pressure as coke-oven seals (11 to 18 kg/cm or 65 to 100 pounds per linear inch). All tests were completed with an internal gas pressure of about 175 mm of H_2O (about 7 inches of water).

The first experiments were to determine if leaks could be minimized or eliminated by improving the surface texture of both the sealing edge and the mating block. As expected, over a range of 6450 nanometers down to 1600 nanometers (250 to 62 microinches) the leak rate decreased; but even with the relatively smooth finish, there still was considerable gas leakage. This confirmed the sealing theory outlined previously.

The next series of experiments was to test various "fillers" for possible use as sealing materials. The results of these tests are shown in Table IV-1.

Fluid coke-plant tar and many other materials can be used as sealing materials in the laboratory test rig.

Comparing these laboratory results with those developed in field tests, it was concluded that:

(1) If the seal edge of existing coke-plant seals compresses or even "touches" tar or tarry materials on the jamb, a complete seal is made because the pressure differential across the seal edge is not high enough to force out the sealing material.

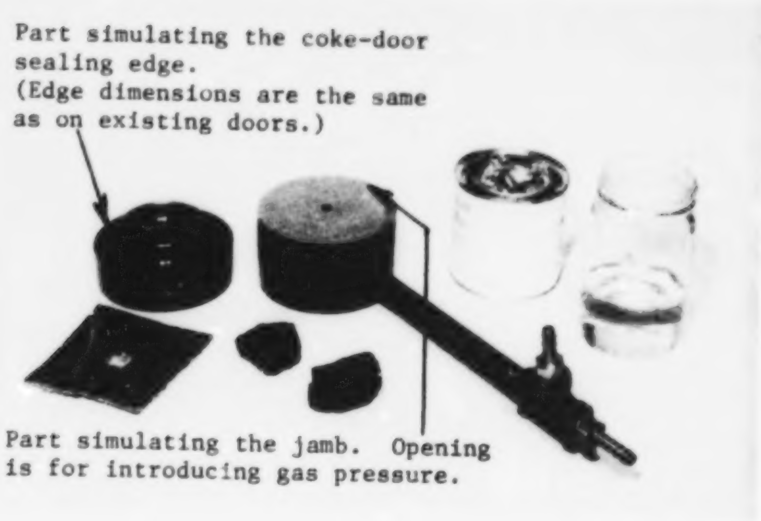

Part simulating the coke-door sealing edge. (Edge dimensions are the same as on existing doors.)
Part simulating the jamb. Opening is for introducing gas pressure.

FIGURE IV-5. BASIC COMPONENTS USED IN LABORATORY METAL-TO-METAL SEALING TESTS

(This equipment was also used to test various potential filler materials.)

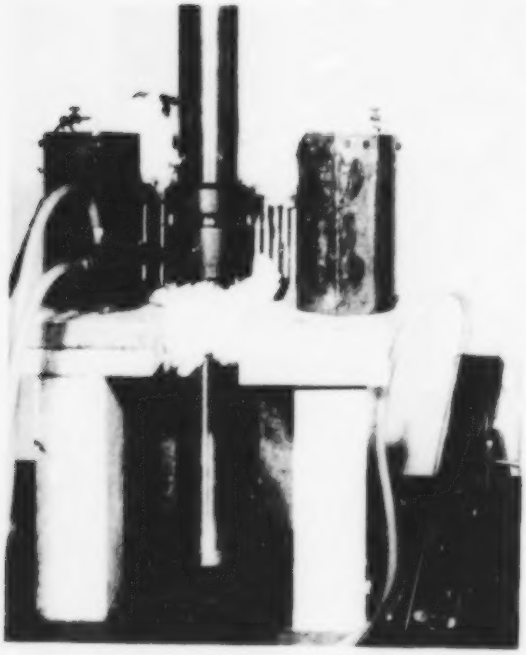


FIGURE IV-6. THE METAL-TO-METAL TESTING EQUIPMENT IN OPERATION

(Test rig is under simulated coke-oven-seal sealing pressure and was heated to coke-oven jamb temperatures by an electric heating furnace.)

TABLE IV-1. SUMMARY OF METAL-TO-METAL SEAL TESTS WITH AND WITHOUT FILLERS

Equipment temperature 260 C (500 F), Mating Pressure 18 kg/cm, Internal Pressure 175 mm of H_2O.

Material	Comments	
	Fine Finish	Rough Finish
Steel to Steel	Leaks slowly	leaks at high rate
Coal-Tar Filler, Commercial	No leaks	No leaks
Coke-Plant Tar	No leaks	No leaks
Roofing Pitch	Hardens, then leaks	Bakes hard, leaks slowly
Corn Syrup (thick)	Boils, no leaks	Boils, no leaks
Molasses	Boils, no leaks	Boils, no leaks
Malasses and Lime	Hardens, no leaks	No leaks
Paper Maché (wet)	Leaks	Leaks
Silver Seal Compound(a)	No leaks	No leaks
Asbestos Sheet, 1/8-Inch(b)	Leaks slowly	Leaks

(a) Silver Seal Compound is commercial high-temperature sealing material. Laboratory tests at 260 C (500 F), in air, indicate that this compound hardens in about 4 hours.

(b) Increased mating pressure eliminates leaks with this material.

(2) If there is any gap (no filler material) on any portion of the seal edge/jamb interface, there is leakage, with the rate depending on the size of the gap and the internal pressure.

(3) Gaps permitting emissions are either plugged or dammed off only after condensation of adhering viscous liquids or semisolids begins at the seal/jamb interface.

(4) This test rig, or a modified test rig, could be used to evaluate seal materials for new concepts, existing self-sealing doors, or the older luted-door designs.

(5) The use of filler materials should be considered as a concept for totally sealing doors, i.e., for complete elimination of emissions. The range of possibilities includes sealants usable for only one cycle, sealants with a life of many cycles (with and without cooling), and others.

Field-Test Results

Early in this project, it was decided to complete week-long visits at selected plants to obtain project data. At a meeting with representatives of the sponsorship, it was decided that Battelle should concentrate its measuring and evaluation efforts on the size and type of the vast majority of coke plants in the country; i.e., the standard 3.4-meter to 4.0-meter oven (11 feet, 2 inches, to 13 feet, 2 inches) of the Koppers and Wilputte design. Testing was completed at a battery in Chicago and a battery in Youngstown, Ohio. The results of these testing programs are grouped and reported in terms of specific areas of interest.

Observations and Comments on Visible Emissions From Doors

Observations Made During the Test Program in Chicago. In Chicago, the investigators were working with a newly rebuilt coke-side door equipped with a fixed-edge seal design.

Individual fixed-edge door seals are "matched" to a particular jamb configuration by adjusting the diaphragm-deflection bolts the first time the door is latched to an oven. In theory, after this initial adjustment the seal edge continues to assume the shape of the jamb when pressed against the same jamb and continues to seal cycle after cycle; i.e., the subsequent adjustments are supposed to be minor.

When the test door was first latched to an oven, the workers spent 37 minutes tightening and adjusting the diaphragm-deflection bolts. During this period, the empty oven was under coke-oven-gas back pressure, and the tightening program was aimed at stopping burning leakage.

On the first cycle of the test door (i.e., after the coal was in the oven), a small amount of visible emissions became apparent. An additional 10 minutes spent in tightening selected diaphragm-deflection bolts resulted in lowering the visible emissions to a trace level. In about 30 minutes after the last adjustment, all visible emissions had stopped.

On the second cycle, the initial level of visible emissions was about two or three times the amount of the initial level on the first cycle. The major emission site was in the vicinity of the top latch on the right side. Subsequent jamb-distortion measurements indicated that this was the location where the jamb had a depression (inward bow).

On the third cycle, the initial level of visible emissions was minor, i.e., about the same as on the first cycle after the second adjustment of the door. Those visible emissions that were released were again at the right side at the upper latch.

As the pressure built up in the test oven on the fourth cycle, a rather heavy leak developed on the left side. This is the opposite side from the leakage in the first three cycles. The leakage on the left side was fairly heavy down by the bottom latch with a "horizontal streamer" at the top of the door on the left side as shown in Figure IV-7. The term "heavy" is used with reference to the first cycles on this test door.

FIGURE IV-7. "STREAMING" OF EMISSIONS FROM A TEST DOOR

Photographed from bottom of doors.

Measurements of the position of the door on the oven indicated that in this fourth cycle the door had been positioned to the extreme left limit of the door guide. With reference to the previous cycles, the door was found to be positioned further left on the jamb by about 3 mm (1/8 inch). It was reasoned that because of the door-position shift, the seal edge was now against a slightly different jamb "shape" than it had been adjusted for. In 3 hours, the visible emission from the door decreased to a wisp. The internal pressure in the oven at the bottom of the door after 3 hours was only about 5 mm of H_2O.

It was noted that each cycle of the oven resulted in a slight general increase in the thickness of the semisolid deposits on the jamb. However, in an emission location, the deposits on the jamb formed in a single cycle were visibly thicker. The thickness of deposits on the door and seal area remained almost constant or increased in thickness only slightly. It was reasoned that visible emissions from locations where there is a gap between the seal and the jamb are sealed by the more rapid buildup of deposits on the jamb in front of the gap. The first three cycles on this test door showed visible emissions from the right side by the upper latch, the location of an obvious gap between the seal and the jamb. The deposits on the jamb in this location were relatively thick by the start of the fourth cycle and, with the shift in the door position to the left, the seal edge pressed into the thick deposit on the jamb. This entry of the seal edge into the thick deposit effectively stopped the emissions from this location on the jamb. Examination of the jamb after the fourth cycle showed the imprint of the seal edge in jamb deposits at this location.

A few general observations made at this plant were found to be true also for other coke plants. It was noted that the rate of buildup of deposits in the gas passage on the door was low. In plants where the deposits in this location are both thick and in some instances hard, it seems reasonable to conclude that no cleaning of the passage had been done for months. There is, however, one reservation to this conclusion. It was noted that in almost all cycles some coal falls between the door liner (door plug) and the oven wall and enters the gas passage on the door. In such cases, sticky clumps of coal/tar mixtures can accumulate rapidly. In this regard, it should be noted that no coke plants operating with 3.4-meter to 4.0-meter ovens are equipped with mechanical cleaning equipment; i.e., all cleaning is done manually. Manual cleaning is both awkward and difficult and is, therefore, usually not done thoroughly, if at all.

Another observation of interest is that on different locations on a coke door, the "self-sealing" of gaps (by deposition of tars on the jamb) proceeds at different rates. Visible emissions from the bottom half of any door "self-seal" rather rapidly (up to about 60 minutes) even though this is in the higher pressure sector of the door. On the other hand, visible emissions from the top portion of the doors often take hours to "self-seal" and can continue visible emissions for the entire cycle. This is true although the pressure inside the oven at these delayed-sealing locations is controllable at a positive pressure level as low as 6 mm of H_2O (about 1/4 inch). Temperature measurements indicate that there is an increase in jamb/seal edge temperature from the bottom to the top of the door. It was concluded that "self-sealing" is a function of deposition rate of tars and that where the equipment is hotter at and near the top of doors, the deposition rate and the related "self-sealing" rate are retarded.

Observations Made During the Test Program in Youngstown, Ohio. In Youngstown, the investigators were working with a rebuilt pusher-side door equipped with an S-shape seal design.

Door seals of the S-shape type (see bottom-right sketch, Figure III-17) are intended to adjust automatically to any oven on a battery, providing the warpage of the jamb is not too pronounced. This adjustment or accommodation is obtained by spring-loaded plungers pressing against the back of the S-bend. The theoretical adaptability of being able to place a door with a flexible seal on any oven on one side of a battery is a desirable feature and would be a desirable feature of any door developed from a new concept. This approach permits routine repairs and maintenance of the door at the end of the battery without adding to the emissions problem. It is suggested here that a leaking door be replaced on the next cycle with a replacement door.

The research team observed the first four cycles on this rebuilt door and noted that, in all instances, the entire seal edge around the door was completely free of visible emissions from the moment the door was placed on the oven. Throughout the cycles there were some slight visible emissions from the chuck door.

The buildup of tars in the gas passage over four cycles was small. In fact, the sheen of the stainless steel surface of the gas passage was still visible. The buildup of deposits on the jamb was only a trace amount. Again, however, it was noted that some coal entered the gas passage and formed sticky clumps that partially blocked the gas passage. At this plant, the doors are manually cleaned almost every cycle.

When this particular test door was at Battelle for the mounting of thermocouples, an 0.8-mm (1/32-inch) hole was drilled through the upstanding seal edge, near the bottom of the door, to serve as a "known-size leak". On the fourth cycle of this test door, this hole was opened prior to the charging of coal into the oven. The 0.8-mm hole streamed visible emissions for 35 minutes, with the volume of emissions being an approximate function of the internal pressure in the gas passage. Final "sealing" occurred rapidly, just as if the hole had been suddenly plugged with high-viscosity tar. Unfortunately, with the door on the oven, it was not possible to reach the hole and to reopen it to determine the rate of sealing later in the cycle. This test lends credibility to the hypothesis that the first volatiles to reach any sealing strip are not capable of sealing small gaps. Stated another way, the high-pressure period at the start of a coking cycle is also the period when the volatiles released in the oven do not seal leaks.

At this battery, it was noted that on every cycle a nearby door had very heavy visible emissions coming from the upper-right latch area and all across the top of the door. Because the location of these emissions was at the hottest part of the door, there was only a minor decrease in emission over an observed 3-hour period. It is indicated, as previously noted, that "self-sealing" does not occur very rapidly at the top of doors.

After a period of 11 weeks, the research team returned to Youngstown to examine the emission-control performance of the test door. The door now had a heavy visible emission from a localized area at the left upper latch. Examination of this location at the end of the cycle indicated that the seal edge had heat buckled and opened a gap. Sketches of the side and front view of the buckled seal strip are shown in Figure IV-8. From a front view, the buckled strip had a slight "S" shape. From the side view, there was a depression (gap) of about 2.4 mm (3/32 inch) over a span of 150 mm (6 inches).

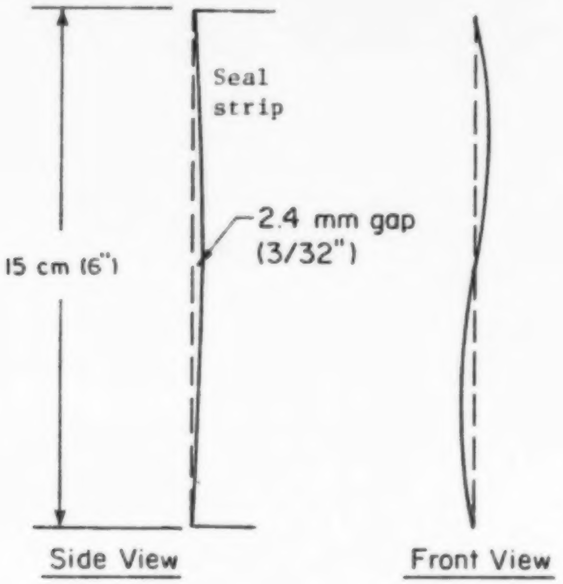


FIGURE IV-8. SKETCH OF THE SIDE AND FRONT VIEW OF A SEAL-EDGE BUCKLE AT THE UPPER LATCH AREA OF A PUSHER-SIDE DOOR

(The wave in the buckled section is similar to the wave in a leveler bar discussed in a later section of this chapter.)

An examination was then made of about 12 doors at other locations on this battery. For about half the doors examined, the heat warpage effect shown in Figure IV-8 was present on both sides of the door at about the upper latches. Further examination indicated that in all instances where the seals were buckled at the sides, the S-shaped sealing strip above the upper latches was permanently deformed outward from the jamb. This was true regardless of the condition of the springs pressing the plungers against the back of the S-shaped sealing arrangement. This was also true of the test door which had only been in operation for about 3 months. A side view of the deflection of the S-shaped sealing strip on the test door is shown in Figure IV-9. This measurement was taken with the door off the oven. The points of buckling may also be locations of mechanical-stress concentrations superimposed on existing thermal stresses.

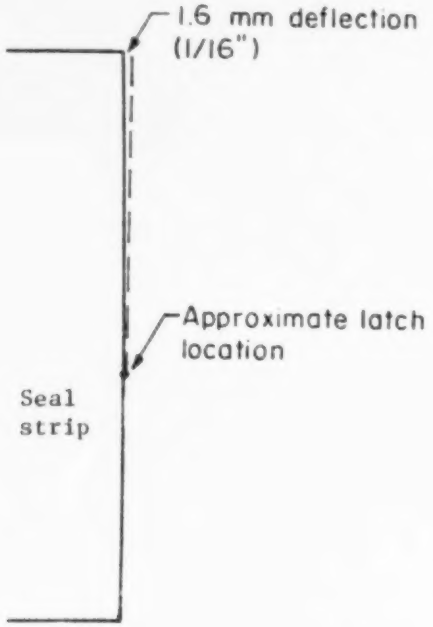


FIGURE IV-9. A SKETCH SHOWING THE PERMANENT OUTWARD (AWAY FROM THE OVEN) DISTORTION OF THE SEALING STRIP ABOVE THE UPPER LATCH

The pattern of outward deflection of the upper seal coupled with the buckling of the seal strip near the upper latches is not believed to be the result of any mechanical damage to the door. Instead, it is believed to be another example of the heat warpage of door/seal/jamb components under thermal cycling coupled with the restraint of movement of these parts. Heat warpage is discussed in a later section of this chapter.

In the return visit to this coke plant, it was observed that this company was now using 3-mm-thick (1/8 inch) asbestos sheet as a gasket for heat-warped chuck doors. In many instances, this use of a complete square of asbestos paper between the chuck door and the casting on the coke-oven door made these chuck doors free of visible emissions and free of deposits on the chuck door and on the mating face of the casting mounted in the coke-oven door. When the gasket did not result in a tight seal, the sealing edge on the chuck-door seal edge was so distorted that the resulting gap was wider than the thickness of the asbestos paper. This was confirmed by placing the gasketing material on the casting and closing and then opening the chuck door. When the sealing edge did not mark the paper in all portions of the gasket, the chuck doors leaked.

This chuck-door gasketing procedure was rated as an approach that, under further development, could become a standard procedure. Of concern, however, is the fact that the procedure increases the temperature of the chuck-door-casting housing. It is probable that the cost of the gasketing material can be appreciably lowered below the cost of the asbestos paper used in these experiments.

Temperature Measurements of Jambs and Sealing Edges

Early in this project it was decided that continuous measurements of temperatures of jambs, doors, and seals could contribute to better understanding the warpage problems of coke-oven end closures. To be able to install thermocouples on sealing strips and in the door liners, it was decided to work with "new" doors; i.e., doors just recently overhauled with the installation of new seal equipment and a new door liner (door plug).

Battelle researchers expressed a desire to do temperature recording at an experimental water-cooled, coke-side jamb being tested by a steel company in the Chicago area. Arrangements were made for tests at this location. For additional testing, several selections of battery locations were offered, and it was decided to complete these tests at a battery located in Youngstown, Ohio.

It should be pointed out in this introduction to the temperature-measuring tests that all coke-plant supervisors contacted had strong feelings against giving researchers permission to drill holes into operating jambs for the permanent installation of thermocouples. This was an unfortunate constraint because a major interest of this program was to determine the temperatures of the interior surfaces of jambs; i. e., the surfaces exposed to radiant heat. In this regard, Battelle researchers have suggested to various coke-plant superintendents that the installation of thermocouples inside of new jambs (prior to installation) would give them a record of the temperature variations that are caused by variations in operating practices.

With the limitation that thermocouples could only be installed on doors, jamb temperatures could only be approximated by (a) installing spring-loaded thermocouples that press against jambs, and (b) installing thermocouples fastened on the seal-edge sides close to the contact point between the seal and the jamb. This limited the temperature measurement to the sealing-strip location on the jamb which is, in most instances, about 4 cm (1.6 inches) away from the location which is expected to be the hottest portion of the jamb. This limitation should be kept in mind when examining the following data.

Summary of the Temperature Data Obtained at a Chicago Battery. Prior to the arrival of the Battelle research team, this coke plant had 3 months previously installed an experimental coke-side jamb having a single internal water passage going up the right side of the jamb, across the top, down the left side, and across and out the bottom of the jamb. The location of the water passage in the jamb is shown in cross section in Figure IV-10.

This jamb, but without water cooling, was in position on an oven for about 2 months, after which it was noted by the coke-plant operators that the jamb was already hourglassing (warping by necking inward). Water was then connected to the cooling passage for about 1 month prior to putting on the test door. Unfortunately, on this first trial of a water-cooled jamb, no records were kept on the dimensional changes of the jamb both without and with water cooling.

Seven sheathed thermocouples were fastened to the sealing edge in the locations shown in Figure IV-11. Also on this figure are the temperature data obtained from these seal-edge locations both with and without water cooling.

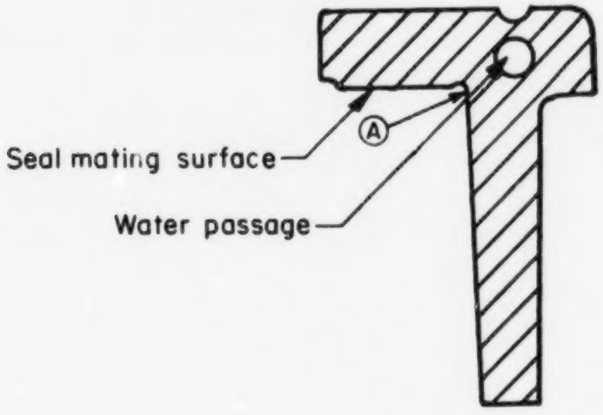
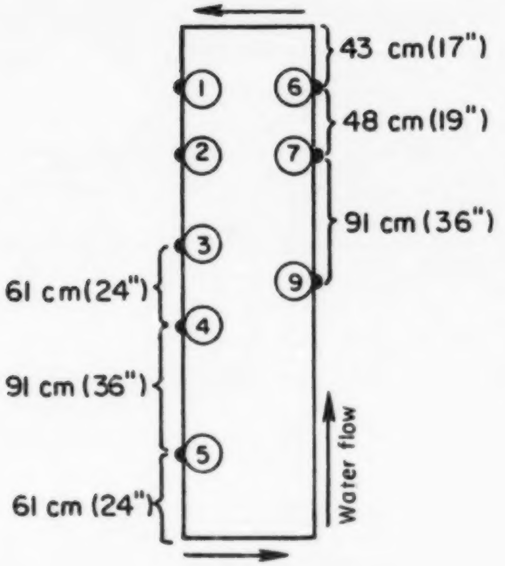


FIGURE IV-10. SKETCH SHOWING THE LOCATION OF AN EXPERIMENTAL WATER-COOLING PASSAGE IN THE CROSS SECTION OF A JAMB



Thermocouple Position	Average Temperature, C(F)	
	Water On	No Water
1	196(390)	260(500)
6	188(370)	263(505)
2	149(300)	260(500)
7	138(280)	238(460)
3	149(300)	232(450)
9	101(215)	227(440)
4	149(300)	243(470)
5	149(300)	204(400)

FIGURE IV-11. SKETCH SHOWING THE LOCATION OF THERMOCOUPLES ATTACHED TO THE SEAL EDGES OF A DOOR AT THE CHICAGO TEST SITE

Also shown are the average temperatures by location depending on whether jamb water cooling was or was not being used.

At the different points of measurement, the use of cooling water lowered the temperature between 55 and 125 C (100 to 225 F) depending on the temperature of the water; i.e., distance from the water inlet. The steady-state thermal loading of the cooling water was about 230 kcal per minute (900 Btu/min).

As was expected, the highest temperatures on the seal edges were above the coal line on the test door.

An interesting feature of the water-cooled jamb is that close to the water passage (at the inner corner of the jamb – Point A in Figure IV-10), the jamb-surface temperature was low enough to permit hand touching. This observation gave credibility to the potential feasibility of sealing concepts using water-cooling to prolong the life of resilient or inflatable seals. A drawback that must be considered, however, is that all of the cooling water would have to be treated, recycled water; i.e., water that would not deposit an insulating film inside the cooling passages. Also, even a brief interruption in the supply of cooling water could ruin expensive special seals.

A thermocouple positioned in the door liner 25 mm (1 inch) from the hot face and 350 mm (14 inches) above the bottom sealing strip responded as expected. With the entry of coal into the oven there was a drop in the hot-face temperature to about 300 C (600 F) in about 5 hours. Following this decline, there was a steady increase in temperature to a peak of about 480 C (900 F) at the end of the cycle.

An observation of interest was the recording of a thermocouple positioned in the gas-passage space between the retaining steel on the door liner and the oven walls; i.e., about 100 mm (4 inches) inside the door diaphragm and 0.9 m (3 feet) up from the bottom of the oven. This thermocouple peaked at about 480 C (900 F) about 2 hours after coal was dropped into the oven. Following this peaking, there was a steady decline in temperature even though the thermocouple was "seeing" an increasing temperature of coal and coke. It was concluded that the thermocouple was, at least partially, measuring the first temperature of the hot volatiles and steam entering the gas passage. One hypothesis has it that the steam and volatiles are finding a horizontal passageway along the bottom corners of the oven.

Summary of Data Obtained at a Youngstown Battery. In this instance, it was possible to send a rebuilt pusher-side door (new Mas-rock liner and new S-shaped seal with spring loading) to BCL for the installation of thermocouples and pressure taps.

The goals of this temperature-measuring program were to:

- Determine the inside and outside seal-edge temperatures with particular emphasis on the chuck-door area
- Obtain jamb-surface temperature close to the sealing-edge thermocouples
- Determine the range in seal-edge temperatures over the entire door for several cycles
- Obtain data on any thermal excursions that occur during the decarbonization procedures
- Use sheathed thermocouples to probe the temperature in the gas passage.

A total of 18 thermocouples was installed inside and outside the sealing edge along both sides of the door. Two were spring-loaded contact thermocouples positioned to press against the jamb. Figure Figure IV-12 is a photograph of the thermocouple and connecting-board installation. An example of the contact thermocouples and the outside seal-edge thermocouples is shown in Figure IV-13. The locations of the seal-edge thermocouples in terms of distances from the top and bottom sealing edge are sketched in Figure IV-14. Figure IV-15 is another view of the installation of the fixed strip-edge thermocouples.

Additional thermocouples were installed at the hot face of the Masrock door plug. These were located 86, 254, and 376 cm (34, 100, and 148 inches) down from the top of the plug.

Pipe nipples were installed leading into the gas passage to serve as internal-pressure taps and also as passageways for temperature probing of the gas passage, including the space between the liner and the oven walls. These taps were installed at the top, middle, and bottom of the door, on both sides.

Summary of Temperature Data. The highest temperatures recorded were always at the top and top sides of the door at the end of the coking cycle. The final peak temperature on the test-door seal

FIGURE IV-12. GENERAL THERMOCOUPLE INSTALLATION ON A TEST DOOR

(During testing all thermocouple lead wires were disconnected from the door during the period when a door was off the oven.)

FIGURE IV-13. INSTALLATION OF A SPRING-LOADED AND A FIXED THERMOCOUPLE MOUNTED OUTBOARD OF A S-SHAPE SEAL DESIGN

Reproduced from best available copy.

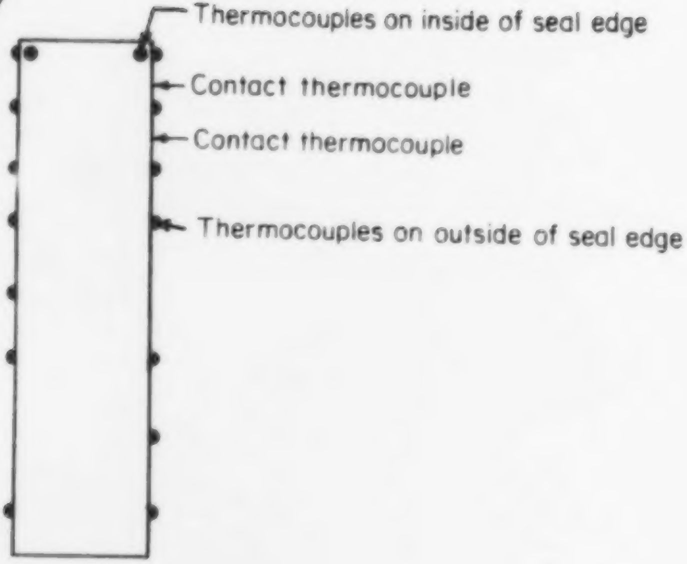

Thermocouples on inside of seal edge
Contact thermocouple
Contact thermocouple
Thermocouples on outside of seal edge

FIGURE IV-14. LOCATION OF THERMOCOUPLES INSIDE AND OUTSIDE THE SEAL EDGE AND THE LOCATION OF SPRING-LOADED CONTACT THERMOCOUPLES

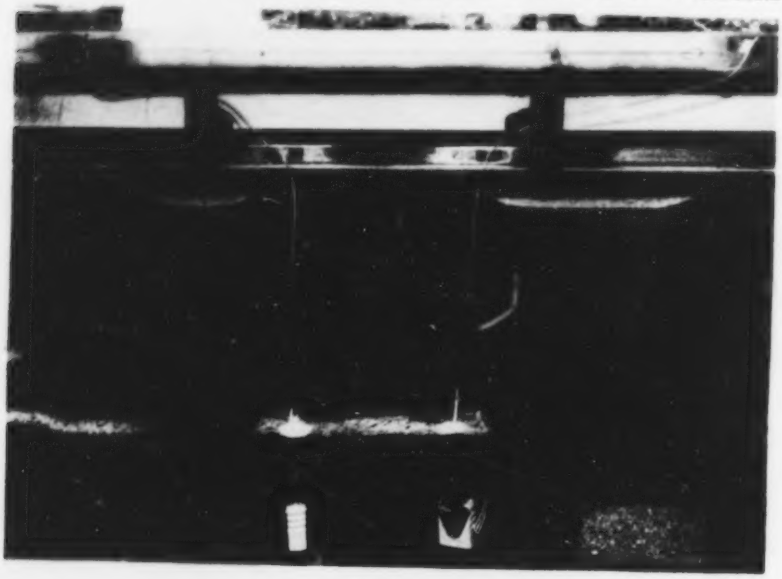


FIGURE IV-15. INSTALLATION OF SHEATHED THERMOCOUPLES ATTACHED TO THE OUTSIDE OF A SEALING STRIP

edges varied from cycle to cycle depending, it is believed, on the length of the decarbonization period. At this plant, the decarbonization of the oven roofs is accomplished by dampering off the valves leading to the collecting mains and opening the two standpipe covers and one or more of the charging ports. This is done prior to the pushing of the oven.

The final temperatures for four cycles of two seal-edge thermocouples located on the inside and outside of the edge and 14 cm (5-1/2 inches) down from the top of the sealing-edge cross piece were as follows:

Cycle Number	Temperature at End of Cycle			
	Inside Thermocouple		Outside Thermocouple	
	C	F	C	F
1	274	525	263	505
2	346	655	335	635
3	235	455	229	445
4	282	540	271	520

These data show variations between supposedly identical cycles. The second cycle recorded had a particularly high final temperature. Various temperatures on the door over the length of this cycle are graphed in Figure IV-16.

It is not known whether or not the general upsweep in temperature at the end of this particular cycle was the result of a prolonged decarbonizing period. However, other cycles recorded on this same oven showed lower finishing temperatures with the next cycle remaining steady at 235 C (455 F) for the top thermocouples for the final 6 hours of the cycle.

The contact thermocouples consistently gave lower readings than the nearby seal-edge thermocouples and were judged to be inaccurate, as contact thermocouples often are.

It is believed that the highest temperature that an oven door/door seal/jamb can reach occurs during production-upset periods when a door is latched on an empty oven for a long time. During this period when a door is on an empty oven, portions of the sealing equipment and jamb are exposed to direct, high-temperature heat from the oven. From a research viewpoint, it would have been very desirable to have

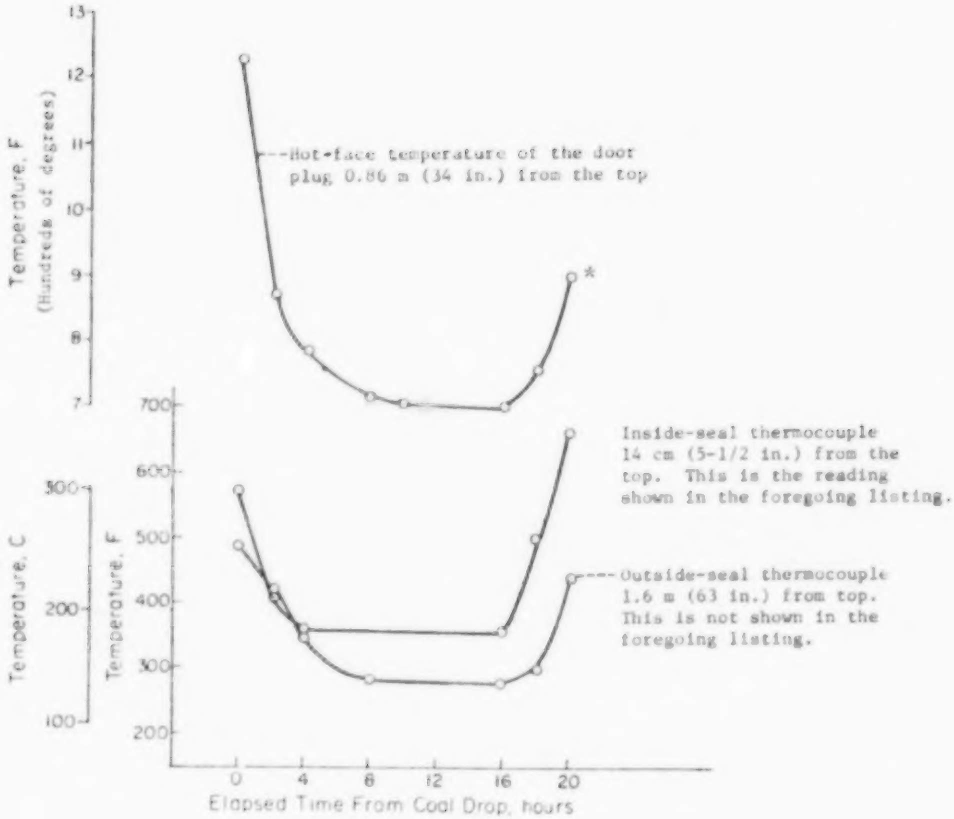


FIGURE IV-16. PLOT OF TEMPERATURES OF SELECTED THERMOCOUPLES DURING THE SECOND CYCLE RECORDED

*All thermocouples were disconnected about 15 minutes prior to removing the door from the oven.

obtained such temperature data, but the dictates of production and absence of a breakdown during the test period made this impossible.

Sheathed thermocouples were inserted through the middle pressure taps into the gas passage of the door and also further into the gap between the door liner and the oven walls. The temperature data were as follows:

Time From Start of Cycle	Opposite Interior Jamb Face	Thermocouple Position Distance Past the Interior Jamb Face 7 cm (3 in.)	13 cm (5 in.)	18 cm (7 in.)
15 minutes	--	515C (960F)	549C (1020F)	565C (1050F)
25 minutes	565C (1050F)	--	--	--
40 minutes	354C (670F)	426C (800F)	--	--

These measurements confirmed other data that the temperature in the gas passage is highest at the beginning of the cycle and falls with time. It is possible that this high heat input into the gas passage early in the cycle can account for the relatively high temperatures of the seal strips at the beginning of each cycle. (See Figure IV-16).

Unfortunately, it was not possible to install thermocouples in any of the jamb surfaces themselves to determine (a) peak temperatures and (b) any excursions in temperature. If this is not done by any one of the coke-producing companies, it is recommended that it should be done on new jambs in any follow-on project.

Dimensional (Warpage) Measurements

At both test locations, measurements were made of the vertical profiles of the jambs (i.e., the inward and outward bowing or distortion of the jamb) and the profile of the seal edge on the door.

The measuring equipment was a Battelle-designed, 3.8-meter (12 foot, 6 inch) collapsible straight-edge. Figure IV-17 is a sketch of this portable straight-edge and Figure IV-18 is a photograph showing the use of this equipment on the seal edge of a coke-oven door.

Measurements Completed at the Chicago Site. Starting with a rebuilt door and a coke-side jamb which had been in operation for about 3 months, measurements were taken of the vertical seal-edge profile and the jamb profile. The presentation of the collected data in Figure IV-19 has foreshortened the vertical dimension, but has retained the actual horizontal displacement dimensions of the end-closure components. All designations as to sides (right or left) refer to the sides when the door is on the oven and observed from the bench.

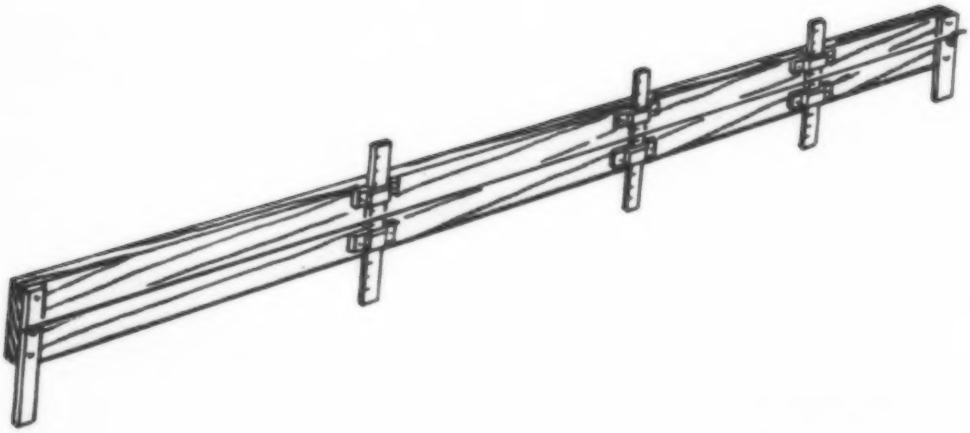


FIGURE IV-17. DRAWING OF A COLLAPSIBLE STRAIGHT-EDGE USED IN OBTAINING THE PROFILE OF JAMBS AND SEALING EDGES

(All distances are referenced to a taut wire between the standoff posts.)

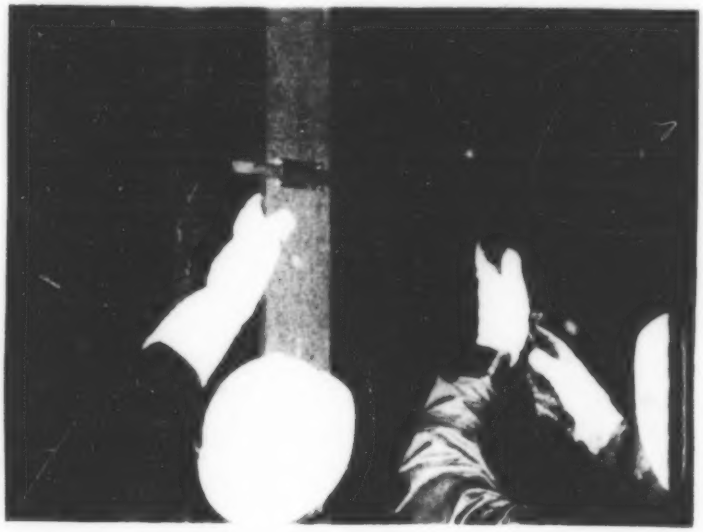


FIGURE IV-18. USING A STRAIGHT-EDGE TO MEASURE THE PROFILE OF A SEALING EDGE

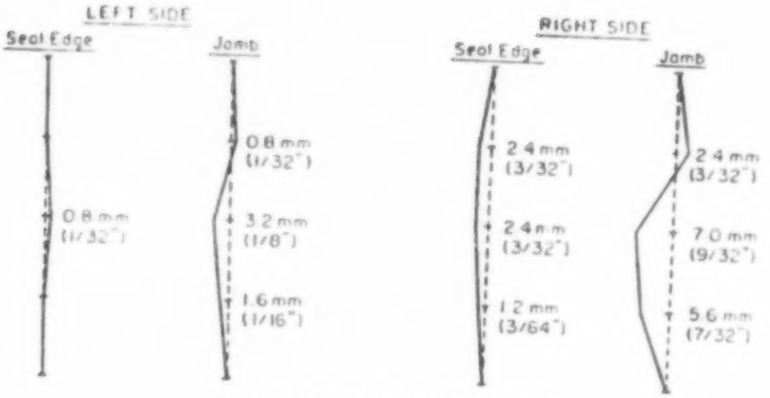
These data indicate that prior to adjusting the diaphragm-deflection bolts on the door there was a calculated 4.8-mm (3/16-inch) gap in the vicinity of the right side of the upper latch. In the section of this report describing the emissions from this test door, it is noted that the emissions from this door were mainly from this gap.

Because of the lack of clearance between the door and the outward extension of the jamb, it was not possible to measure actual gaps between the seal edge and the jamb. All of the gap dimensions indicated above are, therefore, calculated dimensions assuming that there is no thermal deflection of the door and seal edge upon becoming heated. In this regard, it is to be expected that when a door at ambient temperature is first placed on an operating oven, the door frame and seal edge will bow outward; i.e., the portions of the door and seal edge above and below the latches will tend to deflect outward from the jamb, and the center portion between the latches will deflect toward the jamb. The foregoing data then are only an indication of the problems in mating a seal edge and a warped jamb. Various coke-producing plants have attempted with only limited success to measure the deflection of doors when they are first heated. The bowing characteristic resulting from the heating of the door has, however, been confirmed.

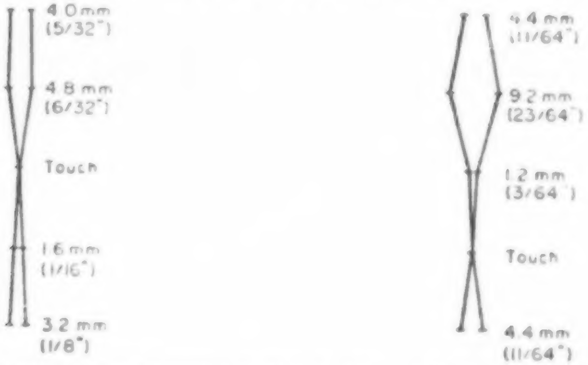
Measurements Completed at the Youngstown Site. The same types of profile measurements were completed at this site with a rebuilt door on an old pusher-side jamb. In addition, a nearby door which was releasing heavy visible emissions was also measured. At this site, the seal profile was measured with the seal and door at operating temperatures. The data collected, presented in the same form as in Figure IV-19, are shown in Figure IV-20.

Over an observation period of about 5 days, the test-door jamb seal was completely free of visible emissions on all cycles, and the nearby leaking door was releasing emissions heavily at the upper latch on the right side as well as across the top of the door.

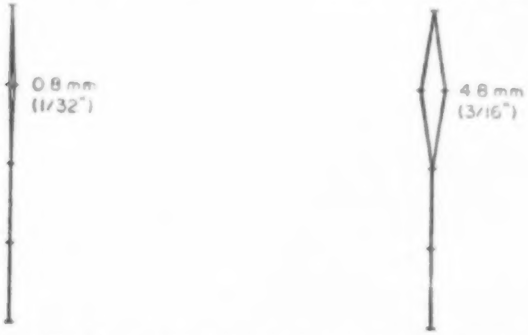
In the door-latching procedure used at this plant, the S-shaped seal is deflected outward until the stop bolts on the door corners seat on the jamb. This deflection is normally about 3 mm (about 1/8 inch). On first touching the jamb (prior to the deflection of the seal), the hot test door had a calculated maximum gap (between the seal and the jamb) on the left side of about 5 mm (about 3/16 inch). Upon deflecting the S-shaped seal the 3 mm (about 1/8 inch) to seat the corner stop



Results of Straight-Edge Measurements



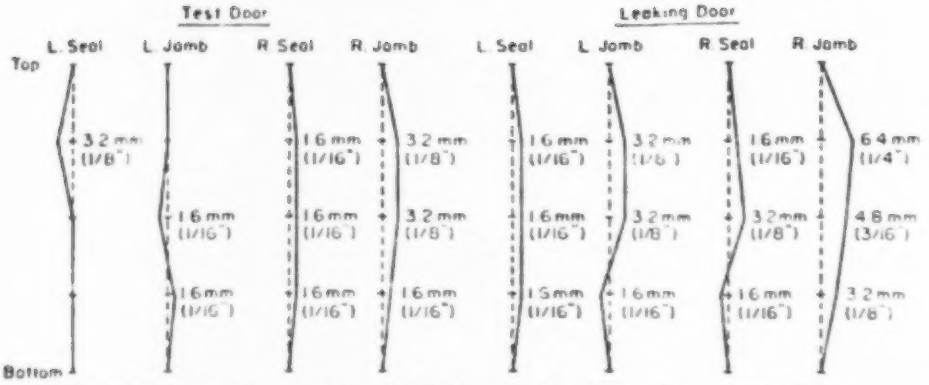
Calculated Gaps Remaining on First Touching of Jamb and Seal Edge



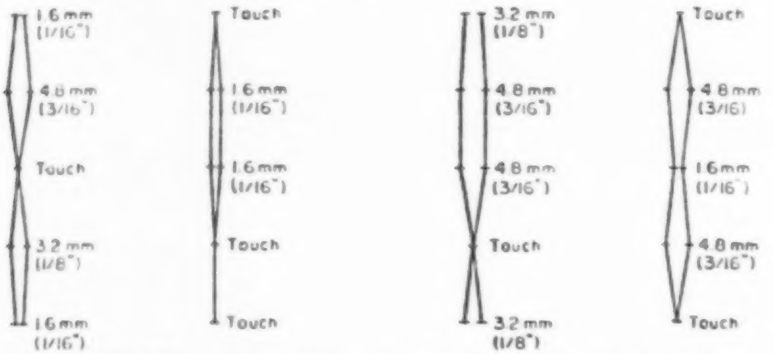
Calculated Gaps Remaining With All Four Corners Touching

FIGURE IV-19. VERTICAL PROFILE OF A JAMB AND DOOR-EDGE SEAL AT THE CHICAGO TEST SITE

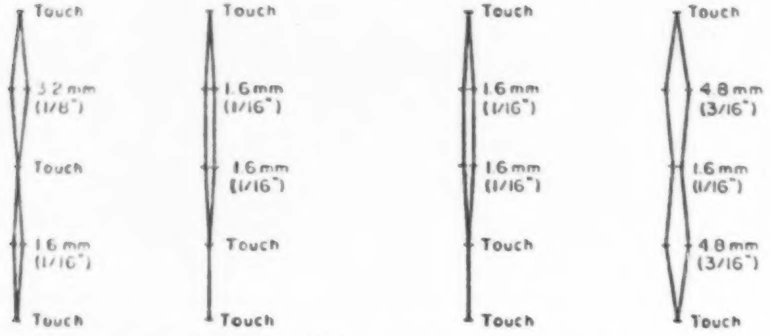
(All vertical distances have been foreshortened, but the horizontal displacements are actual dimensions. The center and bottom presentations are calculated values rather than measured values.)



Vertical Profile of the Door Jamb and Seal Edge on a Test Door and on a Leaking Door



Calculated Gap Dimensions Remaining on First Touching of Jamb and Seal Edge



Calculated Gaps Remaining With All Four Corners Touching

FIGURE IV-20. VERTICAL PROFILE OF A TEST KOPPERS DOOR ON A 10-YEAR-OLD JAMB, AND THE PROFILE OF A LEAKING DOOR ON ITS MATING JAMB

(Only the horizontal dimensions are actual dimensions. The center and bottom presentations are calculated values.)

bolts, the calculated maximum gap (prior to the springback of the seal into the gap) was about 3 mm (about 1/8 inch). Because the seal showed no evidence of leakage at any time, it is apparent that the springback of the loaded S-shaped seal successfully closed and sealed the 3-mm (about 1/8-inch) gap.

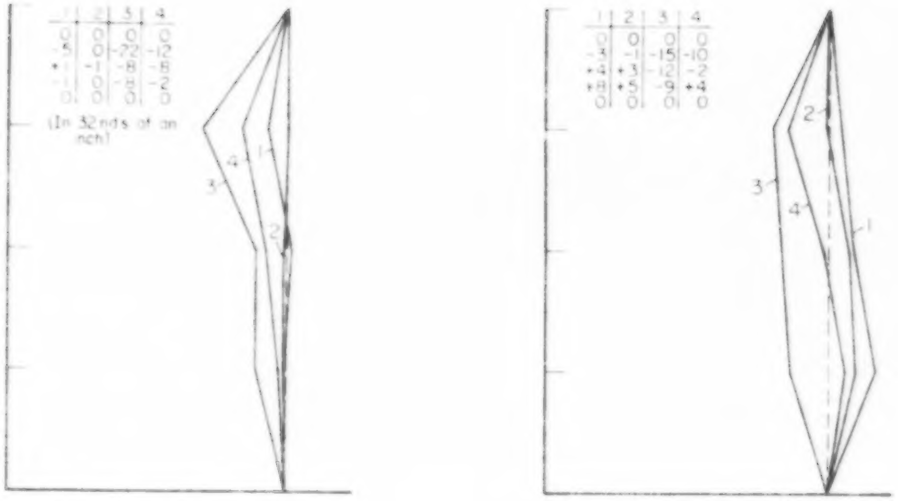
The leaking door had gaps (on seating the corner stops) calculated to be about 5 mm (about 3/16 inch), and these were not sealed by springback deflection of the sealing edge.

Random checks of jambs on the coke side of this battery indicated a wide variation in the degree of jamb warpage. One heavily warped jamb was bowed inward about 11 mm (7/16 inch) at the middle of the jamb.

Jamb Distortion Data From Steel Companies. It became apparent during this study that most companies have not measured jamb distortion, or they regard their data as being unreliable and are therefore reluctant to release these data. However, in one instance, rather complete data were released on measurements on four ovens on both the pusher and the coke sides. These data were obtained by establishing a vertical reference line and then measuring the horizontal distance to the bottom and top of the jamb plus the distances to the midpoint and quarter points.

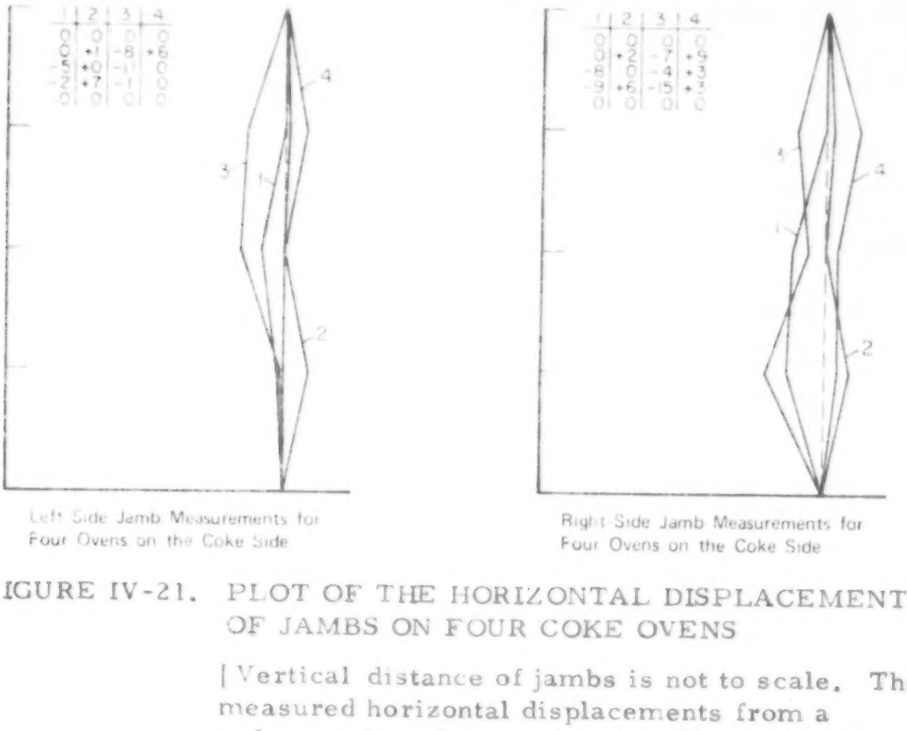
On both sides of the ovens, there was an outward displacement of the top of all jambs relative to the bottom of the jamb. This is common to most coke batteries (if not all) because of the outward displacement of the top of the battery itself. On the coke side, the average outward displacement was 6 cm (about 2.4 inches) with a range of 4.4 to 7.3 cm (1.7 to 2.9 inches) over the four ovens. On the pusher side, the average outward displacement was 5.8 cm (about 2.3 inches) with a wider range of 4.2 to 8.3 cm (about 1.6 to 3.3 inches).

Given the horizontal distance from a vertical reference plane or line to various points on a jamb, it is possible to map the depressions and outward bowing in the jamb surfaces. These data are plotted in Figure IV-21. The vertical dimensions in this figure are not drawn to scale, however, the indicated horizontal displacements from the dashed reference lines are actual dimensions reported in 32nd's of an inch.



Left-Side Jamb Measurements for Four Ovens on the Pusher Side

Right-Side Jamb Measurements for Four Ovens on the Pusher Side



Left-Side Jamb Measurements for Four Ovens on the Coke Side

Right-Side Jamb Measurements for Four Ovens on the Coke Side

FIGURE IV-21. PLOT OF THE HORIZONTAL DISPLACEMENT OF JAMBS ON FOUR COKE OVENS

[Vertical distance of jambs is not to scale. The measured horizontal displacements from a reference line drawn from the top to the bottom of each jamb are actual dimensions in 32nd's of an inch. Negative numbers (left lines) indicate inward jamb bowing (depressions).]

These data indicate that there had been considerable jamb distortion at the coke battery supplying these data. Because this particular battery was experiencing relatively heavy door emissions at the time of Battelle's visit, it is believed that the indicated jamb warpage is about an upper limit relevant to the warpage to be expected throughout the industry.

These data also indicate that there is much more pronounced inward bowing than outward bowing. This is also indicated in the measurements taken by Battelle researchers.

Another conclusion is that there is no particular pattern of distortion on any one jamb; i. e., each jamb appears to develop an individual profile for each side of each jamb.

Internal-Pressure Measurements and Collection of Volatiles. In the measuring programs in Chicago and Youngstown, measurements were made of the gas pressure in the gas passages of the test doors. All of these measurements were made near the botton of the door.

At the Chicago test site, the internal pressure peaked at 100 mm H_2O (about 4 inches H_2O) about 2-1/2 minutes after the start of the leveling operation. At this time, the pressure fluctuations were between 25 and 100 mm (1 and 4 inches). In 30 minutes, the pressure was down to a steady 12 mm (about 1/2 inch). In 80 minutes, the pressure was down to 6 mm (about 1/4 inch), which was the same as the pressure at the top of the oven.

At the Youngstown site, the peak pressure was 125 mm of H_2O (about 5 inches H_2O), but after 80 minutes the pressure was 20 mm (about 0.8 inch).

Throughout most of the coke-producing industry there is an interest in installing a vertical vent or duct in the door liner to lower the pressure at the seals during the initial high-pressure period in the oven. This approach is described on pages III-17 through III-19. Overall this innovation has merit, but it is judged (by Battelle) that (a) it cannot completely eliminate the pressure at the door seal, nor (b) can it lower the emissions that are presently visible at the top or low-pressure portion of some existing doors. The installation of door vents will tend to decrease emissions from the bottom of leaking doors, but much of the observed emissions are from the top third of the door where the vented plug cannot significantly decrease the internal pressure. It is for this reason that the vented-plug concept was not included in the collection of concepts in this report.

At the Chicago test site, some first attempts were made to condense emissions deliberately released through a 6-mm (1/4-inch) pipe installed in the bottom of a door gas passage. For the Youngstown test, a water-cooled copper column was built for condensing these emissions. Condensation was started while the leveling operation was being completed, and was continued with frequent collector-bottle changes for the next 40 minutes. In all of the samples collected, there was a dark, heavy liquid layer and a clear liquid layer. The clear liquid layer was analyzed and found to be water. The dark liquid is believed to be low-temperature coal tar dissolved in solvent-type volatiles. The water was the major portion of the early samples and decreased in relative volume toward the end of the sampling period.

In general, this information lends support to the hypothesis that the majority of the pressure rise developed at the oven doors at the start of the cycle is contributed by steam. The amount of steam condensed decreased with time as the water was driven out of the coal. Given the high percentage of steam and probable presence of only low-boiling volatiles in the steam at the start of the cycle, it is not surprising that gaps or damage points on the seal system do not "self-seal" during the initial high-pressure period of the coking cycle. "Self-sealing" occurs later in the cycle when condensation of higher-boiling point components begins in the seal/jamb area. From this viewpoint, the last leaks to seal would be those where the temperature of the jamb and/or seal is the highest. This would appear to be correct because leaks near or at the tops of the doors "self-seal" very slowly. It is judged that, to eliminate emissions completely from coke-oven doors, it will be necessary to have the door "gas tight" upon latching the door and before the coal is charged. It was judged that water-cooling could improve the rate of "self-sealing", but that it alone is not a direct solution to the emission problem.

Discussion of Heat Warpage of Metallic Components

At coke batteries, gross warpage and distortion of buckstays, door jambs, and frames for chuck doors frequently is evident. In addition, Battelle researchers have noted evidence of heat warpage on the sealing strips on operating coke-oven doors. Many coke-plant supervisors believe that door frames also may be warping over a period of time.

A literature search did not reveal that any stress analysis of buckstays, tie rods, buckstay springs, or door-seal components (jamb/door/seal) has ever been reported. A study and analysis of the stresses (thermal and mechanical) of coke-oven end closures was beyond the scope of this present project, but it is an element to be considered in evaluating the performance of test components in the future. Instrumentation of test components (and also the present end-closure designs) could reveal from the start whether or not new prototype equipment is dimensionally more stable than present structures. Some measure of stability is required to forecast relative performance.

Because of the absence of data on the mechanical forces acting on the end-closure components, the mechanism of warpage can only be hypothesized. However, it is judged that the warpages seen at coke-oven end closures are examples of the adverse effects of prolonged thermal stresses and particularly of thermal cycling.

As an introduction to the subjects of thermal stress and the warpage effects of thermal cycling, a literature search was made in an effort to find an applicable industrial example. Fortunately, a recent report described and analyzed a heat-warpage problem that occurred in a leveler bar at a coke plant in Pennsylvania.* In this case, a new leveler bar of structural carbon steel became distorted so that "the front end raised approximately 160 mm (6.3 inches) starting 6 meters (about 20 feet) back from the nose. At a distance of about 4 meters (about 13 feet) from the nose, the two upper sections of the bar buckled". Figure IV-22 is a photograph of the buckled leveler bar. This leveler bar had to be discarded because it would no longer line up vertically with the chuck doors of the ovens.

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*Stoltz, J. H., "Coke Charging Pollution Demonstration", EPA-650/2-74-022, Prepared for the AISI/EPA, March, 1974.

It is worthy of note that the S-shape form taken at the point of buckling of the leveler bar (Figure IV-22) is also the shape seen at the point of buckling of sealing edges at some coke plants (Figure IV-8). It is this shape that lends credibility to the conclusion that the buckling is the result of heat warpage and not a result of mechanical damage.

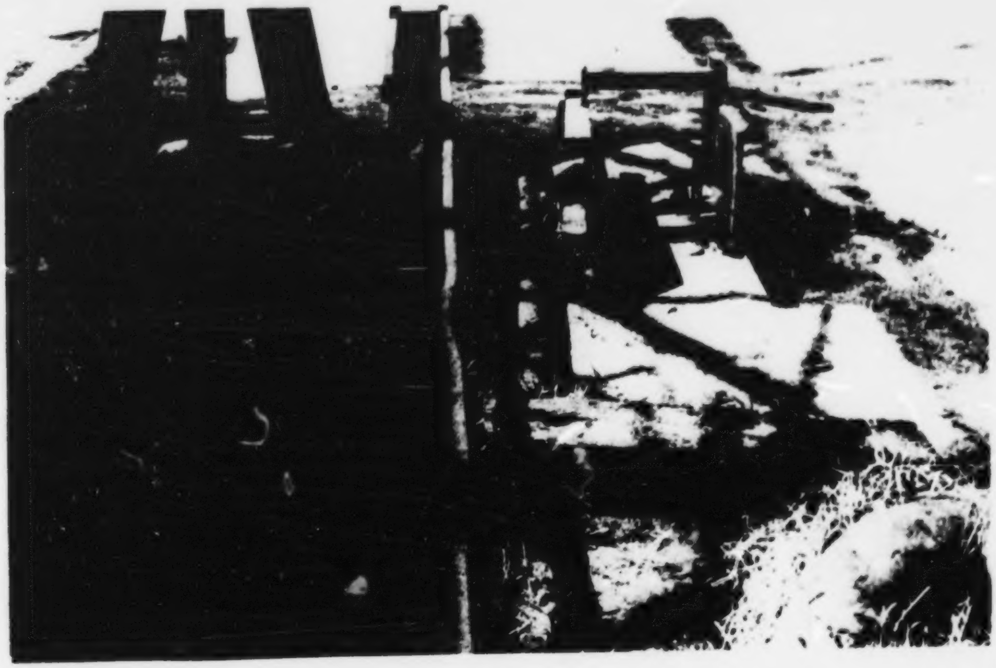

FIGURE IV-22. PHOTOGRAPH OF A THERMALLY WARPED LEVELER BAR

Point of distortion is generally the S-shaped portion.

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Jones & Laughlin Steel Corporation research personnel investigated the leveler-bar distortion problem and concluded that the failure was caused by a differential thermal-expansion effect resulting from nonuniform heating of the bar while the bar was restrained from bending downward. Because the bar was restrained from bending downward (by the coal in the oven), the higher-temperature upper surface suffered plastic (permanent) compression. When the bar was cooled, the top of the bar was shorter than the bottom and the bar reacted to this differential in length by deflecting upward. It was calculated that a temperature difference of only 160 to 240 C (about 320 to 460 F) between the top and bottom of the bar could have accounted for the warpage. It was J & L's recommendation that the leveler bar be made of structural steel having a high yield strength at elevated temperatures.

While it is well known that warpage can occur during thermal cycling without the part or section being under restraint, the application of restraint results in patterns of warpage different from what one would "normally" expect.* The leveler bar, for example, upon cooling bent in the direction of the original heat source because it had been restrained from bending downward during the period when the overheated top of the bar was expanding.

Every coke-oven battery is in cyclic operation and all of its components are subjected to thermal gradients and thermal cycling. In addition, most of the battery components are restrained in one way or another. It is not surprising, therefore, that warpage and distortions become evident after a period of time. The apparent differences in warpage effects from plant to plant are probably a function of the differences in the thermal gradients and the differences in the amount and degree of thermal cycling.

An examination of existing metallic-seal mechanisms indicates that not enough attention may have been given to thermal-expansion effects in the development of the designs. A new sealing strip begins to attempt to expand thermally as soon as it is placed on the oven. The fact that the seal strip and its mounting have a long dimension (4 to 6 meters – 13 to 20 feet) exaggerates expansion effects in the vertical direction. If, for example, the edge of an austenitic stainless steel sealing strip reaches an average temperature of 200 C (about 400 F), then the edge, which is always hotter than the rest of the sealing mechanism, attempts to expand a distance of about 12 mm (about 0.5 inch) over a length of about 4.3 meters (14 feet). It is believed that the temperatures go much higher than an average of 200 C during the period when the doors are on empty (but hot) ovens during periods of charging delays. The sealing strips, however, are either bolted or welded to the support element with no provision to permit thermal expansion. This may be the partial cause for the "wrinkling" noted on door seals, and is the probable reason why there are reports that experimental thinner edges rapidly developed a scalloped shape. The concepts for improved sealing of coke-oven doors (Chapter VI) do not detail designs aimed at resolving the vertical thermal-expansion problem. However, this must be taken into consideration in any development program.

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*Bergman, D. J., "Some Cases of Stress Due to Temperature Gradient", Transactions of ASME, July, 1954, p. 1011.

The heavy H-beam-section buckstays at each end of each oven are designed to provide the required support (compression) for the refractory oven and regenerator walls. In coke-plant operations, the buckstay flange against the battery bricks is warmer than the exposed flange. However, during periods when the emissions from the adjoining door or doors are burning, the buckstays can become very hot with the outside flange remaining at the lowest temperature. Battelle researchers believe that the outward bowing of buckstays is largely the adverse result of door fires only. This judgment is reinforced by the fact that many buckstays that have bowed outward from the battery have developed a clearance between the back flange and the bricks; i.e., there is no continuing outward pressure from the oven bricks or deposited carbon. Also, in many instances, the jamb lugs were not actively pressing against the buckstay. It is judged that this bowing is an example of thermal ratcheting, i.e., distortion by the mechanism of thermal cycling alone. The occurrence and effects of thermal ratcheting are discussed in several papers.* Thermal ratcheting is an incremental increase in the total strain at the end of each thermal cycle, resulting in a continuing increase in deformation. Based on this, solving of the emissions problems at the seals (and from behind the jambs) could eliminate the problem of bowing buckstays.

For the most part, the jambs of coke-oven end closures are complex, rigid, one-piece shapes made of gray cast iron or ductile cast iron. These jambs are subjected to unknown mechanical loads and to variable thermal stresses and thermal cycling. Not much has been reported about the physical loading (pushing of the oven bricks) against jambs, although it is suspected that this is a variable quantity from door to door and from plant to plant. Jambs are either partially locked behind the buckstays or are fastened to the buckstays with lugs. One school of thought in the coke-producing industry is that there is considerable force acting outward against the jamb (and therefore against the buckstay) resulting from the "growth" of carbon behind the jambs. To a degree, the Battelle researchers discount the effect of carbon growth behind the jambs. Instead, it is believed that thermal cycling of the buckstay and jamb can open up gaps behind the jambs, and that these gaps result in (a) emissions and (b) formation of carbon deposits behind the jambs. These deposits are not believed to grow per se, but, rather, the carbon deposit may increase in thickness as the result of further cycles of relaxation, emissions, and carbon deposition. However, overall, the mechanical forces acting on the back side of the jamb cannot be discounted as a contributor to jamb warpage by creep. The reasoning here is that if an expansion cycle can form gaps (and carbon buildup) behind the jamb, a contraction cycle can result in considerable force on the jamb and buckstay.

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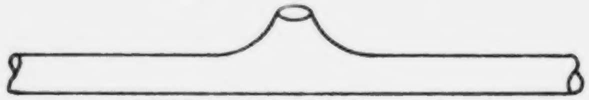
*Parkes, E. W., "Structural Effects of Repeated Thermal Loading", Thermal Stress, Pitman Publishing Corporation, 1964.

Miller, D. R., "Thermal-Stress Ratchet Mechanism in Pressure Vessels", Transactions ASME, 81 D, 1959, p. 190.

Thermal Stresses and Geometry

It is well known that sectional discontinuities can contribute to uneven distortion during cycles of heating. Abrupt changes in the cross sections of the jambs are sectional discontinuities. Sectional discontinuities occur on jambs at (1) corners, (2) latch-plate attachment points, and (3) features provided for mounting the jambs on batteries. The effects of sectional discontinuities on jamb distortion are similar to those which could be produced by any form of inhomogeneity. For example, assume that a round steel bar perfectly homogeneous in every respect is heated uniformly from end to end and also from around the periphery. If this bar were suspended vertically from one end, it could be expected to expand by axial elongation and by uniform increase in diameter. It would remain a straight round bar. But, if a sectional discontinuity were built into the shape of the bar as illustrated below, the bar would deflect by axial bending.



If the uniform round bar were heated uniformly while both ends were constrained from moving linearly, the bar would bend in a smooth, mathematically continuous curve. The bar with the enlarged portion (sectional discontinuity), however, would probably bend in two smooth curves from each end toward the center. The smooth curves would be joined by a relatively sharp change in direction of the curve at the enlarged portion of the bar.

In a similar manner for jambs, the sectional discontinuities occurring at the corners, latch-plate attachment points, and features for mounting the jamb on the oven can produce changes in direction in the otherwise smooth curve of a distorted jamb. At the latch-plate attachment points there are abrupt changes of size and shape of the jamb as well as sharp corners and bolt holes. At the mounting features there are abrupt changes in shape, also associated with holes.

Flexibility and Conformability Limitations of Existing Sealing-Edge Designs

Apparently there has always been a history of jamb warpage over time. This is suggested by the fact that battery designers included a semiflexible metal sealing strip and sealing arrangement and also incorporated high power in the door-handling equipment in an attempt to force the sealing strip to conform to warped jambs. This section deals with the limitations in the present sealing designs in terms of conformability to the degree of jamb warpage that exists on operating ovens. Again it should be noted that the original designers only considered compensating for or adjusting to some limited amount of jamb warpage before they would (and do) recommend installing new jambs. From one viewpoint, this can be considered an oversimplified approach. At least it is oversimplified until such time as a nonwarping jamb design/material is developed.

Neglecting for the moment the complicating effect of the reinforced corners on existing coke-oven sealing arrangements, the sealing action on the tall sides of the ovens is one of attempting to make a steel beam conform to the hills and valleys of bowed (inward and outward) jambs. The shape and dimensions of these beams and the intended directions of flexibility are shown in Figure IV-23. As shown, the height of the upstanding component in both seals is more than the width. These components are, therefore, stiffest in the direction in which flexibility is desired. The thick edge-holder design is significantly stiffer than the thinner design.

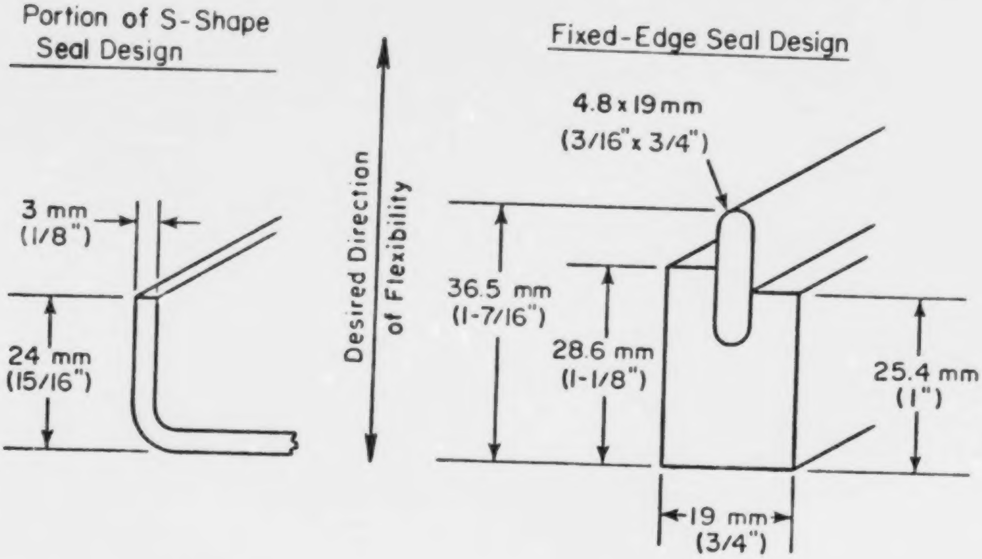


FIGURE IV-23. FULL-SCALE SHAPE AND DIMENSIONS OF THE SEAL-EDGE COMPONENTS OF COKE-OVEN DOORS

Material is carbon steel and/or stainless steel.

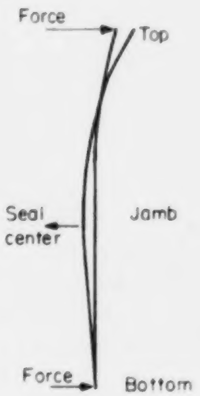
It is probable that the existing dimensions of the sealing sections were developed partially by way of operational requirements. One probable influencing factor, for example, is that heat expansion would buckle thinner sections more easily. It is not known if shorter (less stiff) sections were ever tried.

The dimensions of the fixed-edge holder leads to the judgment that this seal would require more deflection force to conform to warped jambs. With this type of seal, it is worthwhile to consider what jamb "shapes" and applied forces must do to the beam-sealing arrangement.

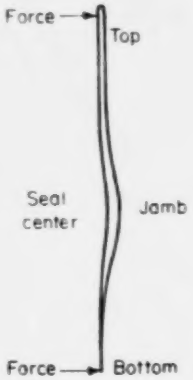
In Example 1, page IV-50, consider a straight-line seal brought into contact with a jamb bent sharply inward at the top. As increased force is applied to produce contact with the top and bottom, the center of the seal tends to spring away from the jamb.

In Example 2, sufficient force has been exerted at top and bottom to close the seal. However, the distorted center portion of the jamb has not been contacted even though the seal has been bent toward the jamb.

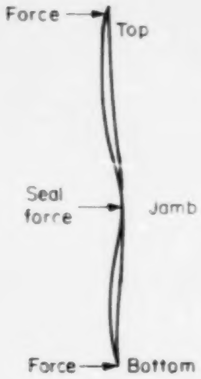
Example 3 illustrates an extension of Example 2 in which additional force has been exerted at the center of the seal to produce contact. This could cause the seal to bend outward from the jamb near top and bottom.



Example 1



Example 2



Example 3

These examples illustrate several basic facts about the deformation of a stiff sealing edge:

(1) If the distortion of the jamb occurs over a short distance, deformation of the seal to conform to the jamb must also occur over a short distance. The distance between peaks or valleys on a warped jamb will be referred to as "pitch" in further discussions.

(2) If the distortion of the jamb is a great variation from the nominal sealing plane, then the seal must also be deflected far from its nominal (or relaxed) plane if it is to conform to the jamb. Distance of the warped surface of jamb from a nominal flat surface is called "amplitude" in further discussion.

It is conceivable that by careful adjustment of bolts between the door and the seal, the seal might be deformed to conform to a distorted jamb. However, the following factors make this a difficult operation, often impossible with present designs:

(1) The workman cannot see the effect of his adjustment directly nor can he directly see the reason for the leakage.

(2) The spacing or location of adjustment points may not be favorable for proper adjustment of the seal.

(3) The force required to deform the seal to match the jamb may be greater than the force provided by the door-latch mechanism or the door-machine latch-drive mechanism.

(4) The pitch of the distortion of the jamb may be so short that it is not possible to force the seal because of its stiffness to conform by bending within its elastic limit.

(5) The amplitude of the distortion of the jamb may be so great that it is not possible to force the seal because of its stiffness to conform by bending within its elastic limit.

The difficulty of attempting to seal a leaking door by adjusting the shape of the seal by pressure from bolts is familiar to every bench workman on a battery. The leak seems to escape adjustment and move around the door as screws are tightened. This phenomenon is illustrated by the preceding three examples of door-seal curvature and is also related to the spacing or location of the adjustment points.

Point (3) (above) that the force required to deform the seal may be greater than the force provided by the door-latch mechanism is possibly the most important. The following discussion explains this situation.

The fixed-edge "diaphragm-pan" seal deforms as a flat sheet or as a broad-leaf spring. Bolts are provided along the edges to permit selective adjustment of the seal-edge contour. As a bolt is adjusted inward (toward the hot side) the seal edge is deflected inward.

However, as one bolt is adjusted inward, the seal edge will deform proportionally to the strength or stiffness of its design and the seal will be raised away from the adjacent bolts. The deformed shape of the seal edge will not, however, fit the shape of the warped jamb in the general case. Bringing other neighboring bolts to bear on the seal edge will not solve the problem because the seal will only move further inward. At this point, the problem might seem to be simply that the bolts can only push inward on the seal and cannot pull outward on it. The fact is that portions of the seal edge adjacent to the point where the adjustment was desired can be moved too far inward so that they hit the jamb where they should not. Therefore, when the door is closed, some latch pressure is required to deform the seal edge locally adjacent to the point where adjustment is required. This requires more force than the force per linear inch of seal specified (average 11 to 18 kg/cm, 65 to 100 lb per linear inch) for sealing, and therefore the sealing force per inch of seal is diminished.

The S-type sealing edge is inherently more flexible than the fixed-edge design, but it also has an inherent flexing problem. However, with this design the problem is limited to inward flexing, i.e., the limited ability of an S-type sealing edge to enter a major depression on the jamb mating surface.

The inherent "outward" flexibility of the S-type or "floating-edge" seal design was established in tests on a rebuilt door and seal. The results of one of these tests are shown in Figure IV-24.

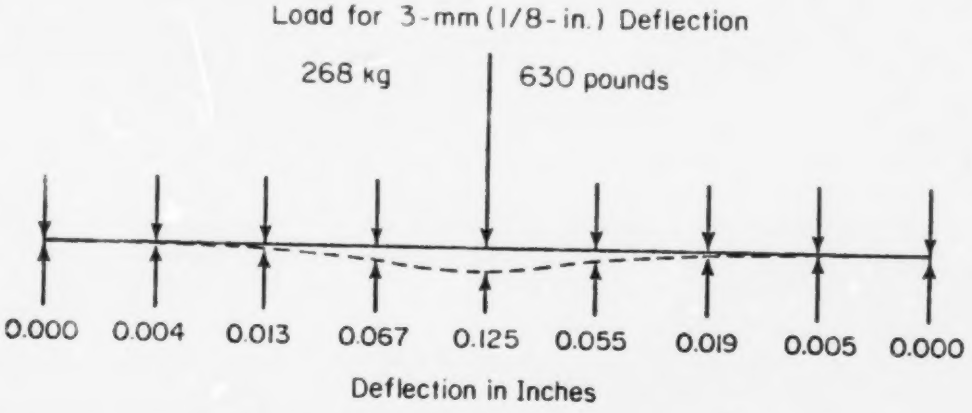


FIGURE IV-24. SEAL-DEFLECTION PATTERN ON POINT LOADING A NEW S-TYPE SEAL ARRANGEMENT

Door and seal were in a horizontal position and the downward deflection is equivalent to an outward deflection on an operating door.

In this experiment, a force of only 270 kg (630 pounds) deflected the seal edge downward (outward from the jamb) a maximum distance of 3 mm (about 1/8 inch). The effect of this single-point application of force caused decreasing deflection about 0.6 m (about 2 feet) on either side of the point of application. It was concluded, disregarding thermal effects, that the S-type sealing design can easily conform to outward displacement of the jamb mating surface. In this regard, the maximum outward displacement of existing jambs in the data available to Battelle was 7 mm (0.3 inch) over a pitch of about 2.4 m (about 8 feet).

However, as previously noted, data on existing jambs indicate that there are jamb depressions (inward bowing from a reference line) of as much as 17.5 mm (0.7 inch) of amplitude over a pitch length of 2.4 m (about 8 feet). With this seal design, it is worthwhile to analyze whether conformity with a deep depression on the jamb is possible.

Some designs of S-seal arrangements have 44 points of spring loading around the periphery of the seal, acting against the back of the upstanding seal strip (see Figure III-17). There is apparently a history of spring relaxation with time and temperature, but, with a new or rebuilt door, the sealing edge is under some "back pressure" at all times; i.e., either on or off the oven. In mounting an S-type seal arrangement on an oven, it is standard practice to attempt to force (and latch) the door on the oven with enough inward force to seat the stop bolts on the door against the four corners of the jamb. This seating action normally results in a backward deflection of the entire sealing edge (if the jamb is completely straight) of about 3 mm (about 1/8 inch). The effect of this deflection is to increase the spring pressure against the back side of the seal edge. However, there is a limitation to the amount of inward deflection this increased force against the back side of the seal strip can cause.

The distance that the seal will deflect inward into a depression on the jamb is a balance of the applicable (and decreasing) spring force and the resistance of the seal material and design. However, the maximum inward deflection conceivable is 3 mm (about 1/8 inch); i.e., a return of the edge to the plane that existed prior to putting the door on the oven. It appears that in order for the S-shaped seal arrangement to conform to deep depressions or valleys on warped jambs, it would be necessary to increase the initial overall deflection via the force introduced by the door-handling machine. For example, if the door stops were set at about 6 mm (about 1/4 inch) and sufficient door-handling-machine force were available to deflect the entire sealing edge this distance, then the S-seal supported by new or unrelaxed springs would have a chance of contacting the bottom of a 6 mm (1/4-inch) depression in the jamb.

It was concluded that there are inherent mechanical limitations in the conformability of both of the two major designs of door-sealing mechanisms. The "fixed-edge" type is particularly inflexible, but it can be forced to deflect into jamb locations having pronounced inward bowing. Once "set", however, this design cannot automatically adjust to the degree of variations in the jamb shape that are believed to occur from cycle to cycle. These variations can come about by lateral variations in the positioning of the doors on jambs and by continuing warpage and flexure of jambs. The S-shaped seal has considerable flexibility in conforming to outward bowing of jambs, but has limitations on conformability to inward bowing. However, a desirable feature of the S-seal approach is the spring action which automatically adjusts to minor variations if these variations are within the limits of the design. It was judged that the designs and materials of fabrication of metal-to-metal contact seals can be improved to minimize emissions.

This discussion of different existing designs of seals does not take into consideration the further complications introduced by thermal expansion and thermal deflection. A complete analysis will require data on heat-caused dimensional shifts and data on levels of stress and strain in the components.

Technical Specifications That New Sealing Systems Should Meet

Study of the causes of emissions from existing metal-to-metal coke-oven sealing systems gave insights into the technical specifications that new sealing systems should meet to minimize emissions and to be considered practical retrofitable solutions. To present these technical specifications, it is necessary to outline the limits of the system being discussed. For the purpose of evaluating the sealing concepts that were developed, Battelle researchers are here defining the sealing system as the existing jambs, doors, and any sealing component, including sealants. Within these limits, the technical specifications for an effective and practical sealing system are as follows:

Specification Number and Name	Specification (and Comments)
(1) Temperature Tolerance	Must withstand the 200 to 300 C (400 to 600 F) temperature pattern in the seal location for prolonged periods of time without deterioration or dimensional changes. (See Figure IV-16 for source of temperature data.) As used here, the prolonged period of time can be years with expensive metal seals or shorter periods if the seals or sealants can be easily replaced and are less costly.
(2) Heat-Excursion Tolerance	Must withstand occasional short periods (perhaps as much as 4 hours) at 430 C (800 F) without being destroyed. Upsets in the operating conditions at coke batteries (equipment failure) can result in such temperature excursions.
(3) Automatic Gap-Closure Capability	With an eye to the future, an ideal sealing system should permit any door to be placed on any jamb on one side of a battery; i.e., no need for manual adjustment of any kind. This specification facilitates rapid replacement of leaking doors from spare or rebuilt stock, with minimum effect and minimum loss of time.
(4) High Gap-Closure Capability	The system should seal most of the gaps caused by the heat warpage of the jambs. Because the warpage data in Figure IV-21 were from a battery having a particularly serious leakage problem, it is thought that this is about the upper limit on jamb warpage to be expected.

Specification Number and Name	Specification (and Comments)
(4) High Gap-Closure Capability (Continued)	Based on these data, it is indicated that the system should seal an inward bow on the jamb face having a maximum "depth" of about 13 mm (about 0. 5 inch). The span of the inward bowing to be sealed is a minimum of 1. 8 m (about 6 feet). The system must also accommodate (and seal) a maximum outward jamb bowing of about 6 mm (0. 25 inch) over a span of 1. 2 meters (about 4 feet) or more. There are some minor combinations of both inward and outward distortions on individual jamb uprights. The most flexible metal sealing systems now in operation can accommodate outward bowing, but have a 3 mm (1/8 inch) limit in terms of entering an inward distortion.
(5) Resistance to Corrosion and Chemical Attack	The sealing system must withstand attack and corrosion by heated gases and liquids for prolonged periods of time without failure. Jambs and seals are exposed to steam, heated organic solvents, coal-tar vapors and liquids and, in some instances, corrosive chlorides from the coal. Some data indicate that the gases can at times be at a higher temperature than the present metal seals (200 to 300 C, 400 to 600 F).
(6) Total-Failure Proof	The sealing system should not be susceptible to the possibility of complete and/or sudden failure during operation.

Specification Number and Name	Specification (and Comments)
(7) Avoidance of New Cleaning Problems	Preferable would be a sealing system that includes the elimination of a cleaning problem, or which functions better with the present cleaning methods. Acceptable is a sealing system that introduces no new cleaning problems that are not clearly solvable.

In addition to these specifications, new sealing concepts should satisfy the six functional requirements. These include retrofitability, dependability, and the other criteria listed in the Introduction of this report (Chapter I) and in Chapter VII where the concept families are evaluated.

Judgments and Opinions on Existing End-Closure Sealing Systems

In meetings with the Sponsors to review the draft of this report, Battelle researchers pointed out that fewer quantitative data (temperatures, stress levels, metal flexure, etc.) had been collected and developed on operating conditions at end closures than had been expected and desired. There is actually very little information within the coke-producing industry on various basic measurements and parameters. Battelle's efforts to define the problem, as presented in this chapter, represent only a start of the research and development work required in this field.

During the review of the draft of this report, the Sponsors asked Battelle researchers to add the following to this final report:

- Judgments and opinions on the existing seal systems
- A listing of the unknowns that Battelle researchers encountered and which could not be answered within the funding of this task
- The investigator's opinions on the special problems of the new sealing systems on the taller ovens (6 meters and higher).

This section is responsive to the foregoing three points, and deals mainly with judgments and opinions based on incomplete quantitative data. Because of the incompleteness of the data, even among the Battelle investigators (who have a wide diversity of backgrounds) there is no unanimity of judgments and opinions. The situation within this group is similar to the diversity of judgments and opinions held by operators of different commercial coke plants. A diversity of opinions will continue to be held by various "experts" until the base of quantitative data is enlarged. The following judgments and opinions are offered to spur continued discussions on the problem and further collection of quantitative data in research programs.

The coke-oven sealing system includes all of the metal armor on the ovens, the doors and their components, the door-handling and latching equipment and procedures, and the cleaning methods used (or not used). Comments on these elements are as follows.

Jambs

Some removable types of jambs are held against the oven brickwork by lugs attached to the buckstays, and other types are almost permanently positioned because they are locked partially behind the buckstays. It is common to hear that there is considerable force against the buckstays either directly from the jamb positioned behind it or from the jambs through the fastening lugs to the buckstays. This force, the variation and distribution of this force, and the possible contribution of this force to jamb warpage are not known. These forces, however, can be measured and should be measured in a follow-on program.

It appears important that the jamb maintain some pressure on the brickwork regardless of the dimensional movements in the jambs, buckstays, and ovens. This does not appear to be possible with the jamb-bolting procedures used on the majority of existing ovens. Consideration should be given to fastening jambs to the buckstays with spring loads pressing on the jamb from the outside, with perhaps resilient refractory insulation cushioning the movement on the oven side of the jamb.

The fact that jambs are heat warped introduces consideration of lowering the temperature of the jamb using insulation and also consideration of analyzing the jamb warpage to develop dimensionally stable jamb design/materials. Any change that would minimize or eliminate the temperature fluctuation in this critical component of the sealing system would be a contribution to stabilization. There is very little information on the temperature fluctuations in existing jambs, and Battelle researchers have no information on the temperature patterns on the newer, taller ovens. Coke-plant superintendents will not as yet permit researchers to "sink" permanent thermocouples into existing jambs because of fear of cracking of the jambs. It is probable that internal thermocouples can be installed in new test jambs of existing and upgraded designs. Battelle researchers believe that recorded thermocouple readings of the temperature at the top of jambs on an entire battery would give the coke-plant superintendent insight into what is going on at each oven for every hour of the day. This procedure would help to identify the operating practices that are causing temperature excursions.

Discussions of the possibilities of insulating jambs with resilient refractory materials (Carborundum's Fiberfrax, Johns-Manville's fiber products, etc.) behind jambs, brings forth expressions of concern about the possible leakage from behind the jambs. Leakage would depend upon the degree of compression of the insulating material, the distance the vapors have to travel horizontally through the insulation, and whether the movement of the jamb (during thermal cycling) will be compensated for by the "bounce" in the resilient refractory. If necessary, foamed (closed-pore) refractory compositions could be developed for this application. Regardless, resilient refractory of any kind should prove more effective than the simple rope packing presently being used behind hot, flexing jambs. Laboratory tests would give insights into whether resilient refractories are capable of preventing leakage.

Even with the development of more flexible sealing elements, some badly warped jambs likely will have to be replaced. Replacement of any jamb is expensive and it could be considered a waste of time and money if the new jamb either starts warping or releases emissions from behind the jamb. This introduces consideration of either substituting upgraded jambs or testing overlay plates on warped jambs (fastened over a layer of insulation) to present a new surface to the sealing edge. This, however, is only a concept at this stage, and further consideration of this approach would require a detailed thermal analysis. This overlay approach has particular appeal for those jambs that are fixed behind the buckstays.

Consideration of lowering the temperature of jambs has to take into account how much heat is arriving at the jamb from the flues and how much is radiant and flame-input heat arriving at the exposed interior surfaces of jambs. It is, for example, important to know whether widening of the door plug (to give a narrower gap between the plug and the furnace walls) would lower the jamb temperature. A thermal model (mathematical) of the operating end of a coke oven could contribute significantly to any seal-development or heat-conservation program.

Operating jambs are either approximately "L" shaped in cross section or, in some of the newer ovens, some of the jambs are sturdy-looking square posts. Cases of extreme warpage have been seen on both types of jambs. The heat stress in these jambs is a function of the thermal gradient (as influenced by thickness and thermal conductivity) and other factors such as the material's coefficient of thermal expansion, the modulus of elasticity, and Poisson's ratio. Gray cast iron has a relatively high thermal conductivity, but its high-temperature tensile strength is low. It is noted with interest that some of the builders of coke ovens are recommending ductile iron jambs which develop a higher thermal stress (under identical shape, size, and operational conditions), but presumably can tolerate the higher stress. It is one of Battelle's recommendations that the design/materials relationships for jambs be analyzed in a mathematical and physical modeling program. A possibility for consideration as a new jamb design/material is high-strength steel plates having improved resistance to creep and relaxation at operating temperatures. Again, however, applied-solid-mechanics specialists prefer to arrive at a solution by analysis rather than indulging in conceptualizing and theorizing. This also holds true for the analysis (and prevention) of the hourglassing problem observed at many coke-oven batteries.

Earlier in this chapter, it was noted that the layer of semiliquid tar deposited on the jamb is the filler material that actually forms the true seal between the metal parts. Stated another way, if successful steps were taken to prevent the tars from reaching the jambs, the metal-to-metal existing seals would leak gas even where there is firm metal-to-metal contact. This is, for example, one of the concerns with the luted-seal concept family described in Chapter VI. With no tars coming to the jambs, it would be necessary to develop either a temperature-resistant, flexible coating for the jamb or to take steps to lower the operating temperature of the jambs so that a switch could be made to resilient seals. Unfortunately, Battelle's search for a coating material that will not harden upon being heated to existing jamb temperatures in air has not been successful. On the other hand, if the temperature of the jambs were lowered, the tars presently depositing on existing jambs would not harden and cleaning would be simplified. With upgraded metal seals that are more reliable in terms of contacting the jambs, the ovens could be emission free and the amount of tars deposited on the jambs, therefore, would decrease. The amount of tar deposited could be further decreased by (a) minimizing the gas-passage area, (b) using a wider door plug (narrower gap', and (c) using a vent in the plug.

As it stands now, there is little doubt that mechanized jamb-cleaning equipment will have to be installed on the batteries that do not have it. Prior to their installation, however, it is suggested that a test program be completed to evaluate the cleaning results after arranging to give the cleaning personnel improved equipment and improved working conditions. Improvement can be made in protecting the workers from radiant heat and in getting the workers closer to the surfaces needing cleaning. With the present manual cleaning methods, the bench man has difficulty in cleaning the important top section of the jamb and his cleaning time is limited by the amount of radiant heat he will or can tolerate. Heat-shields and steps (or elevators) can be installed on the door-handling equipment. It is suggested that the door-machine operators (especially on the pusher side) are in the best position to clean the top portion of jambs. This would be a simple job if a heat shield could be swung into the open oven to allow men to approach the jamb. This cleaning operation has been performed by Battelle personnel (wearing protective equipment), and it was judged to be a simple operation. Cleaning of the tops of the jambs is particularly important in terms of preventing carbon formation in the corners where the stop bolts on some door designs seat. It is not uncommon to see hard deposits in jamb corners. This raises the question of whether the stop bolts are actually seated at some plants.

Doors/Seals

Discussions with coke-plant superintendents and coke-plant builders indicate that some think that doors are flexed inward during the mounting and latching procedure to match the contour of the jamb like two bananas nested together in a bunch. It is agreed that when the back side of a jamb and the oven side of the door casting are first heated, they expand differentially and flex in the same direction, i.e., the jamb can go concave (if it started as a straight casting) and to a degree the door casting will approach this shape. Also, the data that Battelle researchers collected on jamb warpage indicates overall that there is more inward distortion (development of a concave surface) than outward distortion. However, Battelle's calculations indicate that the 5400 kg or more of latching force (12,000 pounds and higher) applied to a door casting on a 3.9-meter oven (12.8 feet) cannot deflect the door casting more than a minute amount. Because of this, after the doorstops seat on the jamb (on one door design), additional application of force may be wasted and is perhaps even damaging. However, various coke-plant operators disagree with this statement, saying that extra force can be helpful in lowering the emission rate from a door. The door-flexure situation is believed to be different on the 6-meter and taller ovens where it has been stated that the doors are very flexible, and according to some opinions too flexible. Overall, a flexing door can be damaging to the door brickwork or door refractory materials. The flexure that is required should be in the sealing arrangement rather than the door. Battelle has no information on door flexure due to heat and/or applied forces other than to state that these movements can be measured and analyzed.

Battelle's calculations (which are really estimates) indicate that the maximum outward force that the peak gas pressure inside the oven can exert on the door is only about 2 to 10 percent of the total latching force. In addition, the coal inside the oven may exert some small force against the inside of the door. The remaining latch force is in theory transmitted to the seal edges, at least on the fixed-edge design of seal. In the S-seal design, the inward force on the door is effective in flexing the seal only until such time as the corner stops on the door seat on the jamb. This point is discussed in other sections of the report. In addition, with the S-seal design there are maintenance problems in keeping the thrust bearing on the door in working shape so that they can transmit the applied screw-down force.* In general, Battelle researchers are recommending that the sealing-edge arrangement be made more flexible and that only sufficient force be put on the door/seal to have the sealing edge enter any depression on the jamb surface.

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*Muller, J. M., et al., "Gary Coke-Oven Door Development Program", Presented at the Joint Meeting of the Eastern and Western States Blast Furnace and Coke Oven Association on October 25, 1974. Copies of this paper can be obtained from the United States Steel Corporation, 600 Grant Street, Pittsburgh, Pennsylvania, 15230.

Even low-pressure contact of the sealing edge and the jamb will prevent emissions, but there must be contact. This is particularly true on a freshly cleaned jamb.

However, improvement in the sealing-edge flexibility can be retrofitted into both types of sealing-edge designs now in existence. As stated in the earlier section on "Technical Specifications That New Sealing Systems Should Meet", it is important that retrofitted designs should have automatic gap-closure capability; i.e., require no manual adjustment of any kind. This can be more easily accomplished with a spring-seal design. It can, however, be accomplished with the fixed seal (see Figure IV-23, page IV-49) if (a) the seal support is redesigned to achieve flexibility and (b) if independent mechanical force can be applied to the back of the seal support after the door is mounted on the oven. It is considered probable that this approach would involve expensive retrofit, but equally distributed force against the back of the flexible seal edge will drive the seal into contact with the inward bows on the jamb.

In the judgment of some coke-plant operators, the most difficult cleaning problem on coke-oven end closures is the manual cleaning of the entire height of the gas passage. This may be correct at some plants, but of those plants observed by Battelle researchers (in the test programs), it was judged that gas-passage cleaning would be simplified if (a) coal could be kept out of the gas passage, (b) the hot tar collected at the bottom of the gas passage was removed on every cycle immediately upon opening the oven, and (c) the amount of tar entering the gas passage and collecting at the bottom of the gas passage could be decreased. In fact, the hot tar could probably be drained off some time in the cycle.

A severe cleaning problem, and one contributing to additional problems, is the progressive buildup of carbon and/or carbon/pitch on the sides of the door plug. This material is particularly difficult to remove manually. If tight-fitting doors could be used on ovens, it is judged that this would minimize (a) coal entry into the gas passage, (b) the gas-pressure buildup at the seals, and (c) the amount of tars and volatiles that enter the gas passage. Ways should be investigated to operate with tighter door plugs. This would include development of methods for occasional nonmanual cleaning of door plugs, improvement of the patching methods on the ends of ovens, and upgrading the door-handling machinery to control accurate placement of the doors on ovens. In addition, there is a probability that this approach would lower the jamb temperatures or minimize the temperature excursions on door jambs.

Door-Handling Machinery

It is a functional requirement of this program that the concepts developed be "compatible with existing door-handling and oven-end working equipment". Although this is a requirement, it is suggested that the capability of such existing equipment should be upgraded.

The swinging of the door and the inward/outward motion of the door-handling equipment should be interlocked to permit only one motion at a time. Battelle observers have witnessed door plugs being damaged (by striking the latch hooks) by operators attempting to swing and place the door all in one motion.

At other locations, Battelle observers have seen operators attempt to come to a stop on an electric-eye spotting point without having any slow-travel capability built into the equipment. The "slop" or loose tolerances in the power train resulted in the operator overshooting the target from one side to the other. It is suggested that the existing power trains be used only for large movements along the battery, i.e., to bring the equipment "into the ball park". Auxiliary equipment should be used to spot the equipment exactly. This could be done in various ways including the installation and use of a hydraulic piston that attaches itself to the rail to obtain a firm support. It is appreciated that coke batteries shift dimensions with time. However, accurate placement of doors on jambs can be developed so as to eliminate or minimize damage to the doors and seals.

It is normal to see door-machinery operators spend up to a minute attempting to increase the latching force on screw-type latches by repetitively jogging the tightening motor. This operation could be upgraded with the installation of larger motors and the use of replaceable, calibrated, slip-type clutches. Also, with the screw-type latches there is concern with the problem of erratic door-latch pressures resulting from damaged thrust bearings. Test equipment can be developed to indicate the latching force without the use of special latch hooks. Battelle personnel, for example, estimated latching forces by measuring the depth of the impression made on strips of lead taped to the latch bars.

Overall, it is judged that the door-handling machinery can be and should be upgraded to (a) prevent damage to the doors and seals, (b) spot the door exactly, and (c) install and latch the door as per specification. Such upgrading will contribute to better sealing and to containment of potential emissions from the ovens.

CHAPTER V

POTENTIAL TECHNOLOGY TRANSFER

Sealing problems are common in many applications over a wide range of conditions. It was considered possible that advanced technology in other fields might be adapted to become effective sealing methods for coke-oven doors.

Technical Objective

The technical objective of this task was to search other industries and other technologies for possible elements of technology and design which might be transferred to conceptualization of new coke-oven door-sealing systems.

Expanded Objective

In addition to making a search of possible transferable sealing technology from other industries and other technologies, Battelle-Columbus in its research proposal outlined the desirability of conducting small-group conferences for idea generation/technology transfer. The participants in these sessions were to be members of Battelle's professional staff who are recognized for their combined innovative ability and knowledgeability in various fields of technology.

Further, it was foreseen that (a) some sealing concepts would center on the use of resilient materials to effect a seal and (b) conditions at coke-oven doors may be beyond the limits of various commercially available materials. It was for these reasons that those researchers assigned to this technology-transfer task were also asked to explore the thermal capabilities of new elastomers, resins, and other nonmetallic materials.

Literature Search

A major portion of this search was done by machine using the key-word approach. This search included the following sources:

Source	Coverage
Engineering Index	10 years
NASA A, B, N, and X Series	1962 to present
NTIS Report Literature	1964 to present
DoD Report Literature	10 years
AEC Related Literature	6 years
Foreign Literature Search	10 years
Air Pollution Abstracts	5 years
Applied Science and Technology	12 years
British Coal Utilization Research Association	10 years
Coke Review	22 years

In general, the return on this investment of time was low. The results of the searches suggest that certain conditions at coke-oven seals are unusual if not unique. These conditions include the large ratio of height to width of the doors, temperatures over 260 C (500 F), and exposure to hot tars and solvents.

The most promising leads developed were inflatable elastomer seals used on large doors in gas-tight rooms and the patented metallic "S" seals developed by Trouvay and Cauvin of France for high-pressure and high-temperature piping connections where misalignment is a potential problem.

Inflatable rubber-type seals were discussed with the two manufacturers in the United States. The concepts that were developed are shown in Concept Family No. 4 (Chapter VI). The "S"-type metallic seals of Trouvay and Cauvin (Paris, France) are shown in Figure V-1.

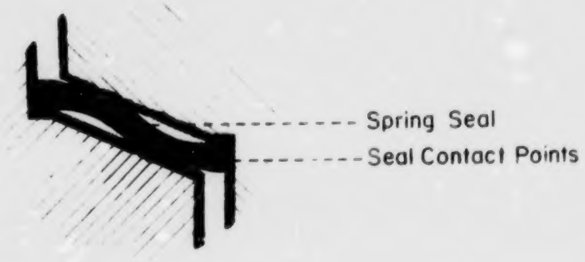

FIGURE V-1. "S"-TYPE METALLIC SEAL

The Trouvay/Cauvin approach is of interest because this company has stated that these seals (a) are demountable, (b) can function at temperatures up to 600 C (1100 F), and (c) do not require close tolerances in the mating surfaces. Variations of this approach have been considered to some degree in Seal Concept Family 5 (Chapter VI). This French company has not responded to letters asking for information about the royalty considerations involved in using either this seal or a variation of this seal.

Survey of Resilient Sealing Materials and Resins

A search for high-temperature elastomers and reinforced resins for possible use as a flexible contact strip was conducted mainly by contacting government agencies and their suppliers. The Air Force Materials Laboratory and other agencies have been supporting research to increase the temperature resistance of elastomers and plastic composites.

It is not unusual to read announcements stating that "a new plastic that can withstand temperatures to 430 C (800 F) and is stable at 370 C (700 F) has been developed by....". Investigation in all instances revealed that stability of plastics is rated on a relative short-term basis; sometimes as long as 2000 hours, but often much shorter.

The consensus that developed is that there is no plastic that will not deteriorate at 315 C (600 F) or even at 260 C (500 F). This is in agreement with the information developed during tests at coke ovens where Teflon (rated stable at 260 C) deteriorated and flowed under pressure in a few month's time. It was concluded that if plastics had an application on coke-oven seals, it would be necessary to water-cool these materials.

Small-Group Technology Transfer and Innovation

Technology transfer means literally the use of existing technology in a new and novel application. Achievement of such a transfer requires both a sufficient knowledge of the existing technology to appreciate its ramifications and limitations, and a sufficient knowledge of the problem area to be able to recognize where the existing technology might apply. Today's technology is so broad and complex, and is developing so rapidly, that it should not be expected that a single mind could bring to bear the vast scope desired. Further, different minds view a given problem from different perspectives. Often, the solution to a problem comes from a totally unexpected quarter. Alternatively, a problem may change dramatically in character if one (in the words of medicine) attacks the source rather than treats the symptoms.

For coke-oven doors, the problem is one of sealing the doors to prevent the leakage of hydrocarbon emissions into the atmosphere surrounding the ovens. A large part of the present program has been aimed at the details of this leakage. What is it? How much is there? Where does it come from? Why do leaks develop? What is the environment a successful seal must endure, etc? This information was required not only to enable us to pass judgment on the pros and cons of proposed seals, but also to provide some guidance as to where to look in the existing technology for possible solutions.

As information developed, it was fed to various members of the research team so that a scan of the literature covering seals would be more meaningful. At the same time, realizing the difficulties associated with recognizing potential solutions in the literature, and realizing the possibility that an ideal solution could be missed in such an approach, an additional method was adopted. This was a variation on the "brainstorming" idea.

Basically, brainstorming amounts to assembling an appropriate group of technical people, proposing the problem, and letting the discussion proceed with no negative comment allowed. This generally produces a large number of ideas, most of which are eventually judged worthless when viewed as solutions to the problem. However, even the worst of the ideas sometimes stimulates a cross-link and generates a novel useful idea. Negative comments during the session tend to suppress novel thoughts. Therefore, negative comments are outlawed. Ideas are evaluated later.

The first innovative session was held at Battelle's Columbus Laboratories (BCL). It involved 18 people with broad and diverse backgrounds. Participants were selected on the basis of the research team's personal knowledge of their creative abilities. A brief summary of the problem was presented, along with a movie of coke ovens with leaking doors. Discussion was then initiated on the problem, with a moderator to keep order. In this session some dozens of ideas developed. Subsequent evaluation by the moderator and by the mechanical-design specialists on the project narrowed these concepts and turned some of these into an engineering-concept presentation. Interestingly enough, even the idea list itself was enough to spur continuing creativity during the subsequent evaluation sessions. Thus, several of the proposed seals were conceived after the innovative session, but could be traced in concept to the discussions. Of particular interest was the recognition during the innovative session that a seal close to the tip of the plug might be ideal in that it could prevent condensible gases from ever reaching the conventional seals. This, of course, could eliminate the deposits of coal tar at the conventional seals and would greatly relieve current cleaning and reseating problems.

This concept of "hot-zone" sealing was discussed further with other team members during evaluation sessions. It was at that time realized that, if an appropriate foam could be found, this might provide precisely the sealant necessary. Thus, a search began for a suitable foam, something not considered at all in earlier stages of the investigation. We believe that we may have identified such a foam. It is patented and preparations are currently being made by a manufacturer to bring it to the market place within the next year. Specific details on this foam have been requested from the manufacturer*, but are not yet available.

A second innovative session was conducted at Battelle's Pacific Northwest Laboratories (BNW) in Richland, Washington. There, eight members of the senior staff, with widely varying backgrounds, selected for their creativity and independence of thinking, were assembled. The procedure followed was the same as at BCL, except that that the same moderator introduced some of the ideas discussed at BCL when appropriate to avoid redundancy or to expand the discussion.

While some redundancy was anticipated, it came as a surprise that most of the ideas presented were clearly different from those generated at BCL. At one point, the concept of a "hot-zone" seal was introduced and there followed a series of ideas relative to the use of coke breeze as a sealant, along with the idea of redesign of the oven to permit coke breeze to be poured in next to the plug during the loading of coal into the slot. This is a radically different approach which no amount of literature searching would have revealed.

The procedure at BNW differed from that at BCL in that a second meeting was held the following day. The purpose of the second meeting was to become more specific relative to materials and concepts. Negative criticism was permitted. Again, creativity continued and new thoughts developed as the previous day's concepts were refined.

The results of these meetings were later discussed with the BCL project team, and selected ideas were converted to design drawings.

A digest and summary of ideas generated at the two Battelle laboratories are provided in Tables V-1 and V-2. As the reader examines Chapter VI of this report (Conceptualization of Sealing Methods), it will be apparent that some of the ideas on these lists were expanded into entire concept families and into several variations.

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* Van Leer (V.S). Associated with Royal Packaging Van Leer of Holland.

TABLE V-1. DIGEST AND SUMMARY OF IDEAS GENERATED AT THE BATTELLE-COLUMBUS BRAINSTORMING SESSION

A. Concepts Involving a "Cold Seal"; Fairly Adaptable to Existing Door or Jambs with Minor Modifications

    1. Lute internally, in a groove, combined with pressure sealing(*).
    2. Gun groove shut with pitch-clay, or clay-molasses foam.
    3. Mount seal retainer on jamb; push knife edge into
        - (a) lead or copper
        - (b) asbestos/Teflon
        - (c) spring-loaded fiberglass
        - (d) silicone rubber - water-cooled retainer.
    4. Coat parts with Teflon for easier cleaning.
    5. Spray jamb with mold-release compounds (silicone, graphite in oil, flint powder in binder, edible release compound now sold for household use, etc.).

B. Concepts Involving a "Cold Seal", But Requiring Moderate to Major Redesign of Doors or Jambs

    1. Change seal every time with quick-release mechanism.
    2. Design labyrinth seal.
    3. Use a double seal with the inside seal tight and the outside seal more-or-less loose. Collect emissions at top of seal.
    4. Use a second door (like a garage door) covering the main door. Collect emissions.
    5. Use a corona-discharge wire outside the sealing edge to collect emissions.
    6. Suck out gas from between two seals.
    7. Electrically heated knife-edge to cut into some sealing material such as thermoplastic tar.
    8. Cool sealing edge to accelerate condensation of leaking vapors.
    9. Water-cool jamb to prevent warpage.
    10. Use thin Teflon tubing, water cooled, as sealing edge. Pressurize with water to cool and provide seal.
    11. Provide Teflon tube with tail for easy replacement by shaping the tail into a groove.
    12. Use wedge-shaped door with chevron-shaped seals.
    13. Provide auxiliary pressure for sealing by hydraulic or pneumatic means.

TABLE V-1. (Continued)

14. Provide more sping in knife edge so that it can follow contour better. Use hardened steel to provide more rugged sealing.
15. Introduce "self-aligning" into door to minimize position-shifting.
16. Bolt "add-on" water cooling to jambs.
17. Use twin seals with water flowing between seals.

C. Major Redesign and Operational Concepts

1. Provide seal in gas passage to prevent condensibles from ever reaching existing seals.

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*During the preparation of this Final Report it was learned that on April 1, 1975, Mr. Albert Calderon was issued U. S. Patent No. 3,875,018 dealing with a form of internal luting of coke-oven doors. The Calderon method was not directly evaluated by Battelle researchers, but a general evaluation of luting approaches is included in Chapter VII.

TABLE V-2. DIGEST AND SUMMARY OF IDEAS GENERATED AT THE BATTELLE-NORTHWEST BRAINSTORMING SESSION

A. Concepts Involving a "Cold Seal"; Fairly Adaptable to Existing Doors with Minor Modifications

   1. Add foaming agent to tars as they condense. This would fill space quickly to seal off leaks.

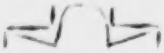
   2. Use silicon foam (good to 600 F or better) as soft reusable seal.

B. Concepts Involving a "Cold Seal"; But Requiring Moderate to Major Redesign of Doors

   1. Self-cleaning or disposable condenser, possibly in gas passage but probably at edge of door; maybe a water labyrinth.

   2. Reorient the seal 90 degrees to battery face. Achieve seal by side pressure either from articulated door or from pneumatic or hydraulic pressure from the sides.

   3. Same as 2, but use Flexatallic seal.

   4. Swing-wing door  to apply pressure.

   5. Put second door (flexible) over plug-holder door.

   6. Seam-weld shut each cycle.

C. Concepts Involving a Gas-Passage Seal; Fairly Adaptable to Existing Doors with Minor Modifications

   1. Disposable nose plug of coke breeze, maybe made into blanket or partially bonded together by coal tars or bentonite clay.

   2. Foamed carbon in gas passage, possibly incorporate breeze.

   3. Suitable preformed foam to abrade and jam into gas passage as door closes.

D. Concept Involving a Gas-Passage Seal but Requiring Moderate to Major Redesign of Oven

   1. Pour coke breeze adjacent to doors along with coal. Coke breeze will fill gas passage and act as trap for condensibles.

TABLE V-2. (Continued)

E. Major Redesign and Operational Concepts

1. Have only one door on bottom of slot.
2. Bury jam in ceramic to minimize temperature gradient and, therefore, minimize warping.
3. Gunite repair of plugs and ceramic surfaces.

F. Materials Possibilities

1. New 1-Mo ductile cast iron may be superior to existing materials.
2. Check boiler grates as possible materials with long-term dimensional stability in thermal-cycling environment.

CHAPTER VI

CONCEPTUALIZATION OF SEALING METHODS

Improved emission control at the end-closures of coke ovens will require an improvement in many of the elements of end-closure systems. The following discussion of concepts deals principally with the concepts regarding seals and sealing techniques.

Approach to Concept Generation

Candidate concepts relating to oven-sealing systems were generated by idea conferences and consideration of current literature and developments in other industrial fields. To assure that ingenuity would not be stifled, a "from-the-bricks-out" attitude was adopted for these conferences.

Preliminary Evaluation of Sealing Methods

As seal concepts were accumulated from various researchers, they were catalogued according to the extent they modified the existing oven designs. Thus, a concept which replaced door and jamb, "from the bricks out", was called a "Category One" concept. A concept which merely added a seal feature to the existing door (or jamb) was called a "Category Five" concept. As more concepts were collected, it became apparent that a somewhat different system of classification of concepts was required to facilitate evaluation of concepts.

A preliminary evaluation of seal concepts was performed by Battelle researchers of various technical backgrounds, already familiar with the research work. In this culling operation, individuals were presented with word descriptions and illustration representing 49 seal concepts. Each evaluator was asked to place each concept in one of three groups, namely:

Group 1: Believed to offer greatest benefits and greatest promise for successful outcome of developmental research

Group 2: No strong feelings for success or failure of developmental research

Group 3: Believed to offer no unique advantage and to hold little promise for successful outcome of developmental research.

As the results of this evaluation exercise were studied, two conclusions became quite apparent.

(1) There was consensus among the evaluators regarding the concepts placed in Group 3.

(2) Groups 1 and 2 did not reveal clear lines of discrimination.

Therefore, it was concluded that this preliminary evaluation could effectively lower the number of candidate concepts by eliminating Group 3. Additionally, as a result of this study of concepts, an important insight into classification of concepts for further evaluation was realized.

Classification of Sealing Methods

Working collectively with Groups 1 and 2 from the preliminary evaluation, it became apparent that these concepts could be regrouped into six families. Figure VI-1 illustrates the logical development of this classification system. Each of the concepts generated could be placed in one of the six classes of concept families.

This grouping of seal concepts into concept families now revealed strengths and weaknesses in each family. Some seal concepts were combined or modified to incorporate more desirable features. Some new ideas were sought to extend the number of design possibilities

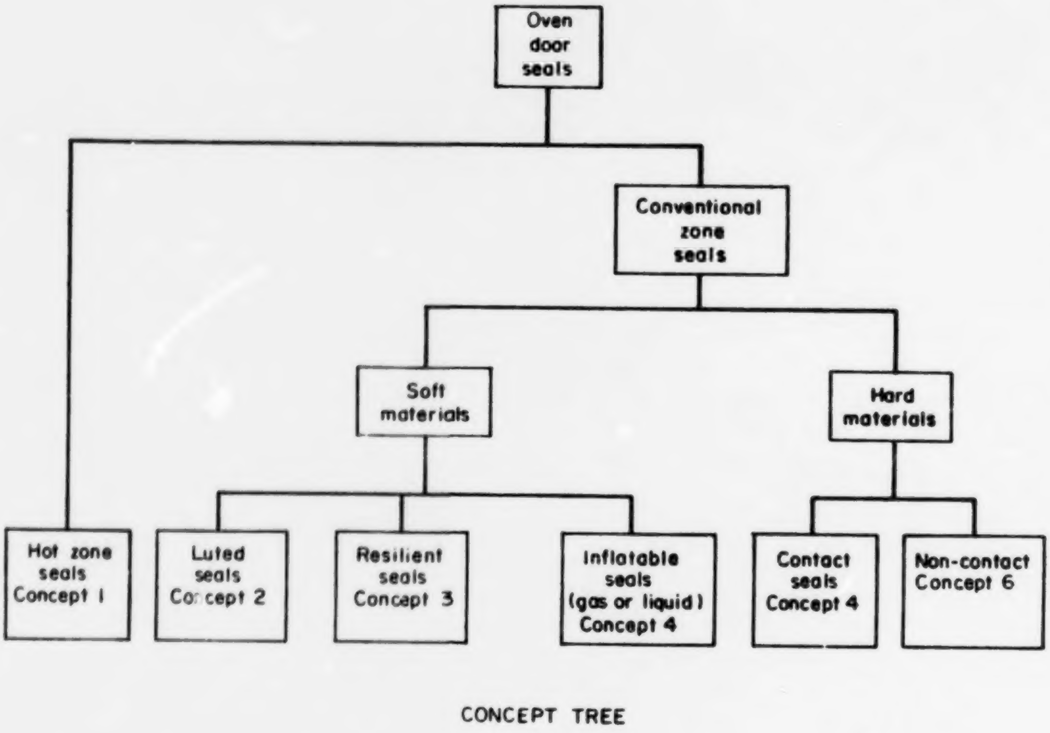


FIGURE VI-1. AN ILLUSTRATION OF THE LOGICAL DEVELOPMENT OF THE CONCEPT CLASSIFICATION SYSTEM

illustrating the possible latitude of each family. The purpose of this system of concept classification was to present concept families, each of which could be represented by numerous design possibilities, for further evaluation. This was done because

(1) Detailed design study of specific experimental sealing hardware was not within the scope of the present program, and

(2) Success of an overall program of such scope and importance should be based on selection of a concept approach which allows many design alternatives for experimental development.

Sealing-Concept Families

This section includes all of the seal concepts classified into families as shown in Figure VI-1. Each concept family is described by illustrations of several design possibilities with related functional explanations. Additionally, each concept family has been synthesized into a complete sealing system. Written descriptions of all major portions of a complete sealing system are included with each concept family. The exceptions to this approach are where there is no requirement for a modification of existing equipment and/or procedures. For example, only one concept has a requirement for a modification to existing oven brickwork. In all instances, existing latch mechanisms in good condition are compatible with all concepts. A measure of good condition is that latching forces would be distributed to the four latch points and the torque of the latch-drive mechanism must be transmitted effectively to the latch plates. No concept requires greater precision in door positioning than present practice. It is suggested, however, that modifications should be made to improve the precision of door positioning. This would include lowering of door-position tolerance with the addition of replaceable guide pads and upgrading the door-machine(s) power train to permit improved positioning control. This could be accomplished with the addition of an auxiliary power unit on the existing equipment.

In general, it is assumed that if a concept can be developed to seal coke-oven doors, it can also be developed to seal the small chuck door(s) on the pusher-side doors. In some instances, it would be necessary to consider ceramic insulation or metallic heat shields to lower component temperatures and attendant heat loss. The adaptation of some concepts might be limited by the cooling which can be provided, either by air or water. Overall, however, the emissions from existing chuck-door seals can be minimized by maintaining the original design objectives. Hinge pins should fit the hinge so that doors are held in alignment with the jamb surface and with the latch mechanism. The latch mechanisms should be free to move so that latching forces are adequately transmitted to the seal. Latch-driving mechanisms should be capable of producing designed forces to close and latch the doors properly. Minor modifications should be made to the chuck-door equipment to improve the serviceability of these features on an as-needed basis.

This chapter describes concept families in the way that they were first presented to the AISI/EPA/BCL judgmental evaluators. This first evaluation was followed by a more technical evaluation by Battelle researchers. It is in this final evaluation (Chapter VII) that details and discussions of materials, problems, and possibilities are included.

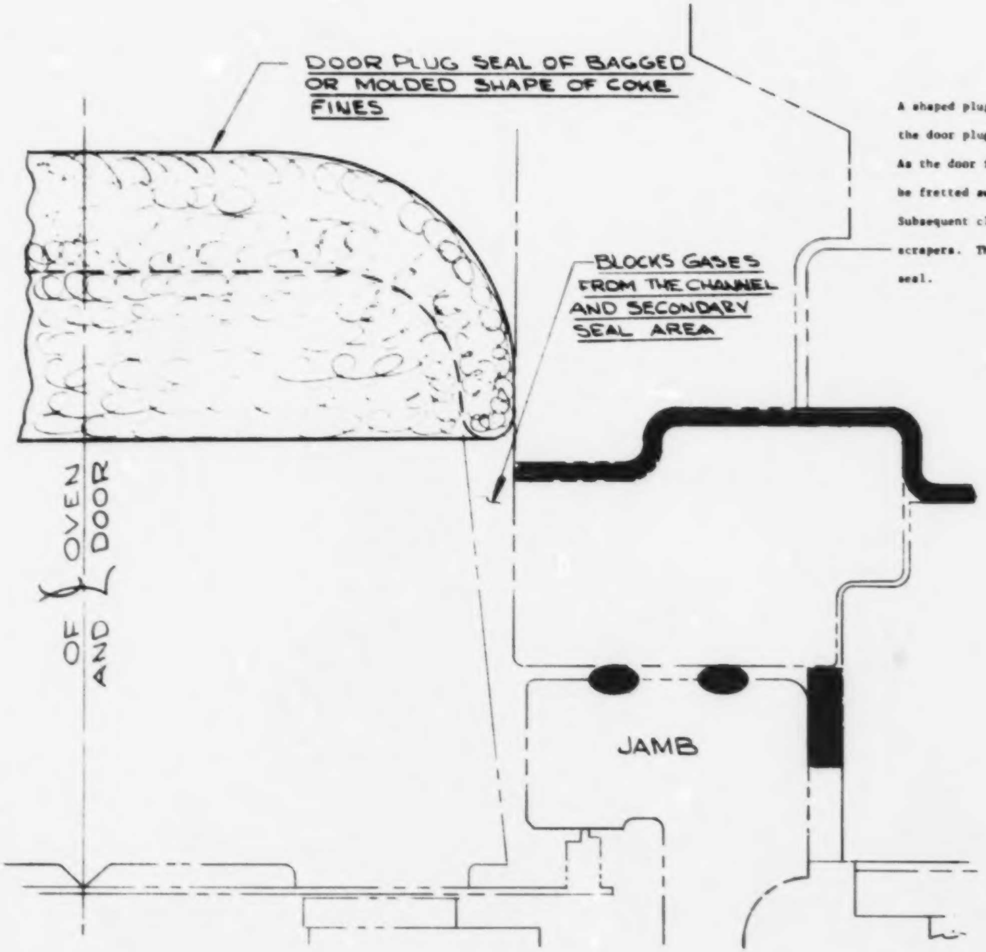
Seal Concept Family 1 – Hot Zone Seals

This concept includes seals located in the hot zone between the door plug and the oven wall, outboard from the end flues, or between the door plug and the coal charge. The intent of this concept is to close off the door-plug clearance area so that (1) coal will not be admitted to that area or to the so-called gas channel, (2) gas pressure will be lowered in the gas channel, and (3) volatile vapors will be significantly lowered in the gas channel, thus minimizing condensation products in the region of the conventional (present) seal. Present materials developments admit the possibility of suitable materials. Frangible foamed ceramics developed for other industrial applications possess some properties similar to those required in coke-oven application of this concept. One example might be the frangible glass foam produced by the Pittsburgh Corning Corp.

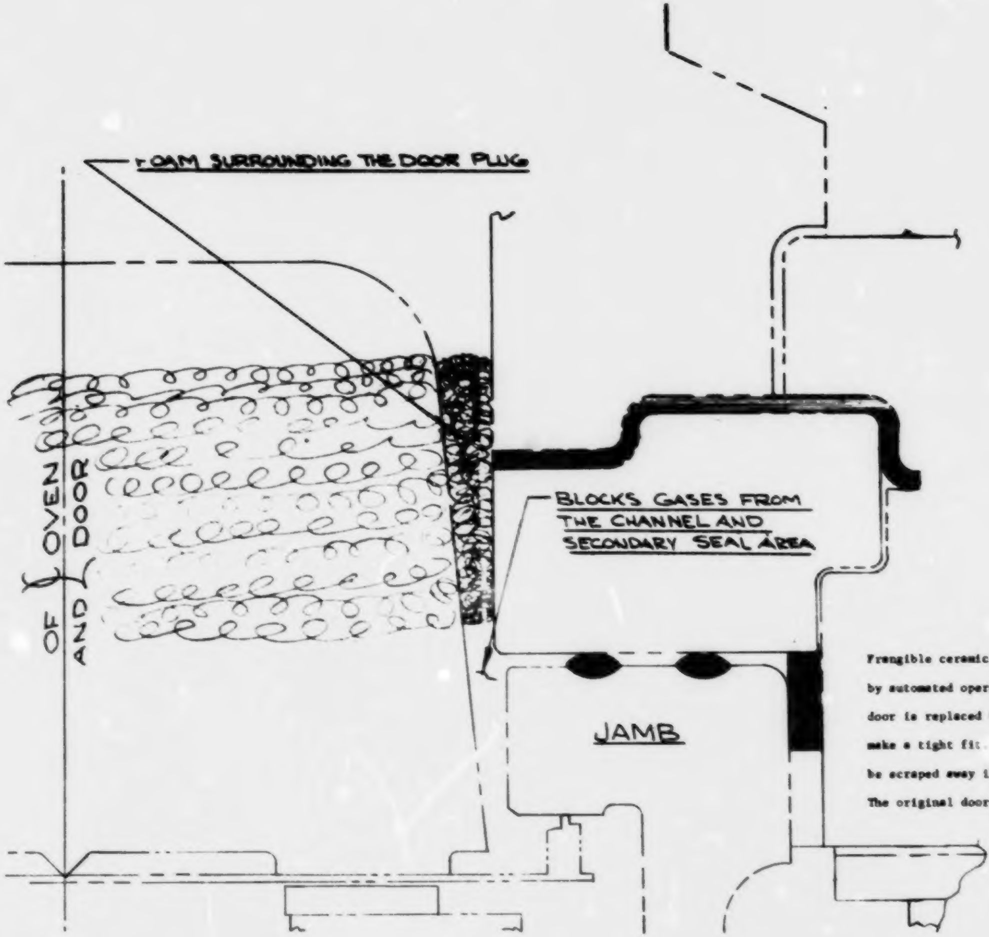
Several design possibilities illustrating this concept are shown in Drawings 1-1, 1-2, and 1-3. The following discussion of the concept refers to these illustrations and reveals relationships between the concept and conventional designs of ovens and operating equipment.

Oven Brick Work. Modifications to oven brick work are not required except by the design possibility illustrated by Drawing 1-3, in which a hole through the oven roof is required behind each door plug.

Door Jambs. Existing door jambs of various designs are compatible with this concept, except that extreme "hourglass" distortion would restrict door placement and removal. Presently acceptable degree of flatness of the jamb is not detrimental to application of the concept.

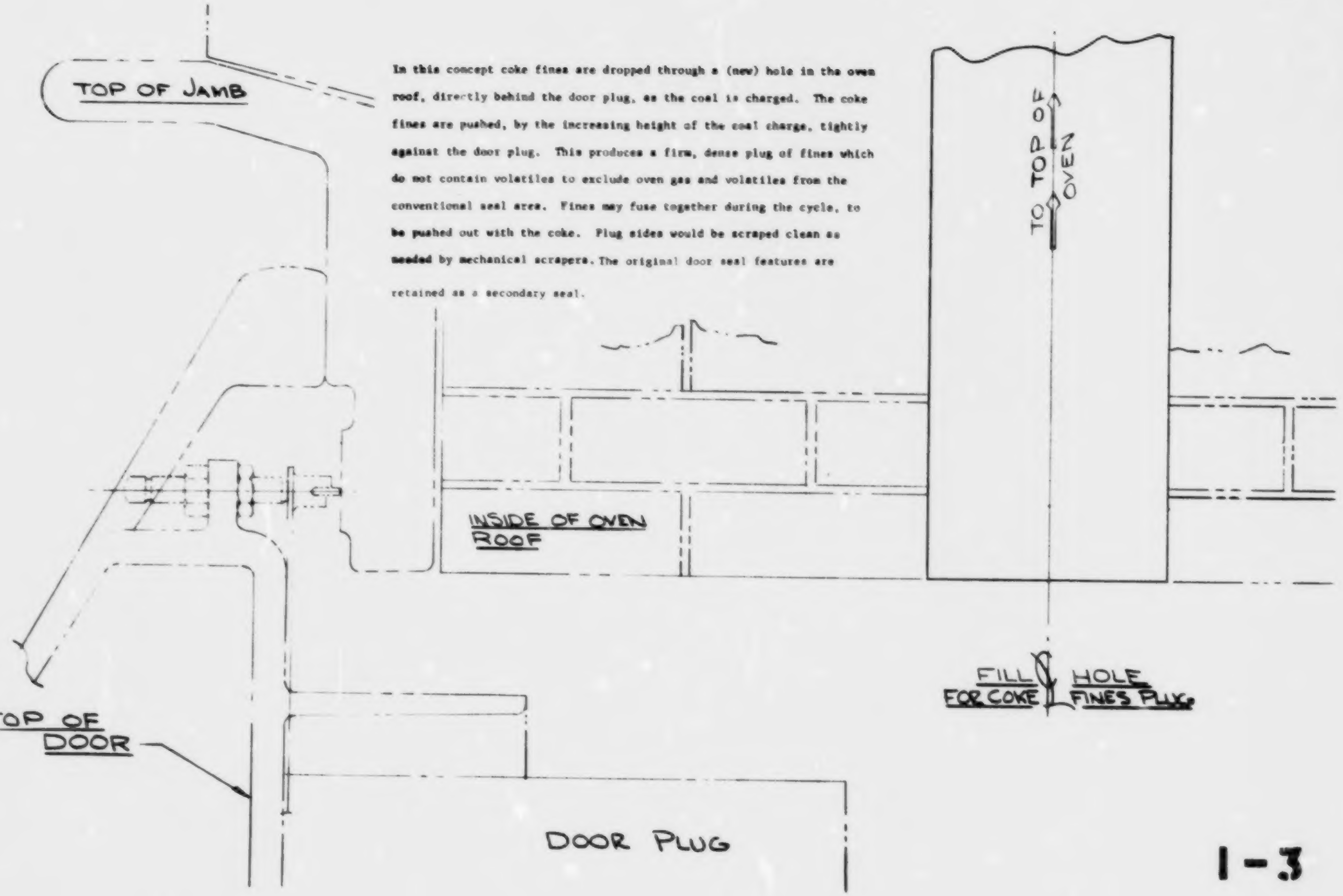

DOOR PLUG SEAL OF BAGGED OR MOLDED SHAPE OF COKE FINES
BLOCKS GASES FROM THE CHANNEL AND SECONDARY SEAL AREA
JAMB
℄ OF OVEN AND DOOR
1-1

A shaped plug seal of bagged or molded coke fines could be placed on the door plug automatically while the door is on the door machine. As the door is installed on the oven the shaped plug of fines could be fretted away by the jamb or oven wall to make a tight fit. Subsequent cleaning of the plug could be accomplished with mechanized scrapers. The original door seal features are retained as a secondary seal.


FOAM SURROUNDING THE DOOR PLUG
BLOCKS GASES FROM THE CHANNEL AND SECONDARY SEAL AREA
JAMB
℄ OF OVEN AND DOOR

Frangible ceramic material would be foamed in place around the door plug by automated operation while the door is on the door machine. As the door is replaced the foam ceramic would fret away on the oven wall to make a tight fit. When the door is removed the remaining foam would be scraped away if necessary and new material would be foamed in place. The original door seal features are retained as a secondary seal.

1-2



In this concept coke fines are dropped through a (new) hole in the oven roof, directly behind the door plug, as the coal is charged. The coke fines are pushed, by the increasing height of the coal charge, tightly against the door plug. This produces a firm, dense plug of fines which do not contain volatiles to exclude oven gas and volatiles from the conventional seal area. Fines may fuse together during the cycle, to be pushed out with the coke. Plug sides would be scraped clean as needed by mechanical scrapers. The original door seal features are retained as a secondary seal.

1-3

Seal Components. Existing door seals of various designs in good condition are compatible with this concept and would be retained as a secondary sealing mechanism. The concept would perform the primary sealing function and the present door-seal would be exposed to lower temperatures and to lower quantities of oven gases and particulates.

Oven Doors. Existing doors of various designs are compatible with this concept and would be retained without modifications, if in good condition.

Cleaning. Sealing media which might remain in the oven would be pushed out with the coke. Sealing media and other accumulated deposits of the coking process which would cling to the door plug would be cleaned periodically by conventional means, preferably mechanized, including scraping or high-pressure water jets. Cleaning of the oven wall would not be required. However, the sill should be shoveled clean each cycle. Jambs and conventional door seals will require occasional cleaning by conventional means, preferably mechanized. Accumulations in this area are minimized by the primary seal which excludes intrusion of volatile vapors and particulates.

Seal Concept Family 2 – Luting Seals*

This concept involves seals located in the conventional zone of existing metal-contact seals. The concept performs the sealing function by the use of formed-in-place material which has the ability to deform to fill and close potential leak paths. Somewhat different than the luting done at older design coke-oven doors, this concept is directed mainly to locating sealants *between* or in some instances inside of the mating metal surfaces. The concept minimizes the need for accuracy of fit between adjacent metal members of the seal.

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* Luting has the present meaning in the coke-producing industry of sealing older-design doors by plastering the *outside* of the mating surfaces with a clay mixture. In this study, the luting concepts consist generally of placing (and compressing) a sealant *between* the two mating surfaces. It was decided not to attempt to coin or originate a new name for this sealing approach because it could develop that the sealant will be applied or introduced either inside or outside of the mating surfaces either before or after a door has been placed on an oven.

Present materials developments admit the possibility of suitable sealants. Frangible foamed ceramics and elastomeric materials developed for other industrial applications possess some properties similar to those required in coke-oven applications of this concept.

Several design possibilities illustrating this concept are shown in Drawings 2-1 through 2-6. The following discussion of the concept refers to these drawings.

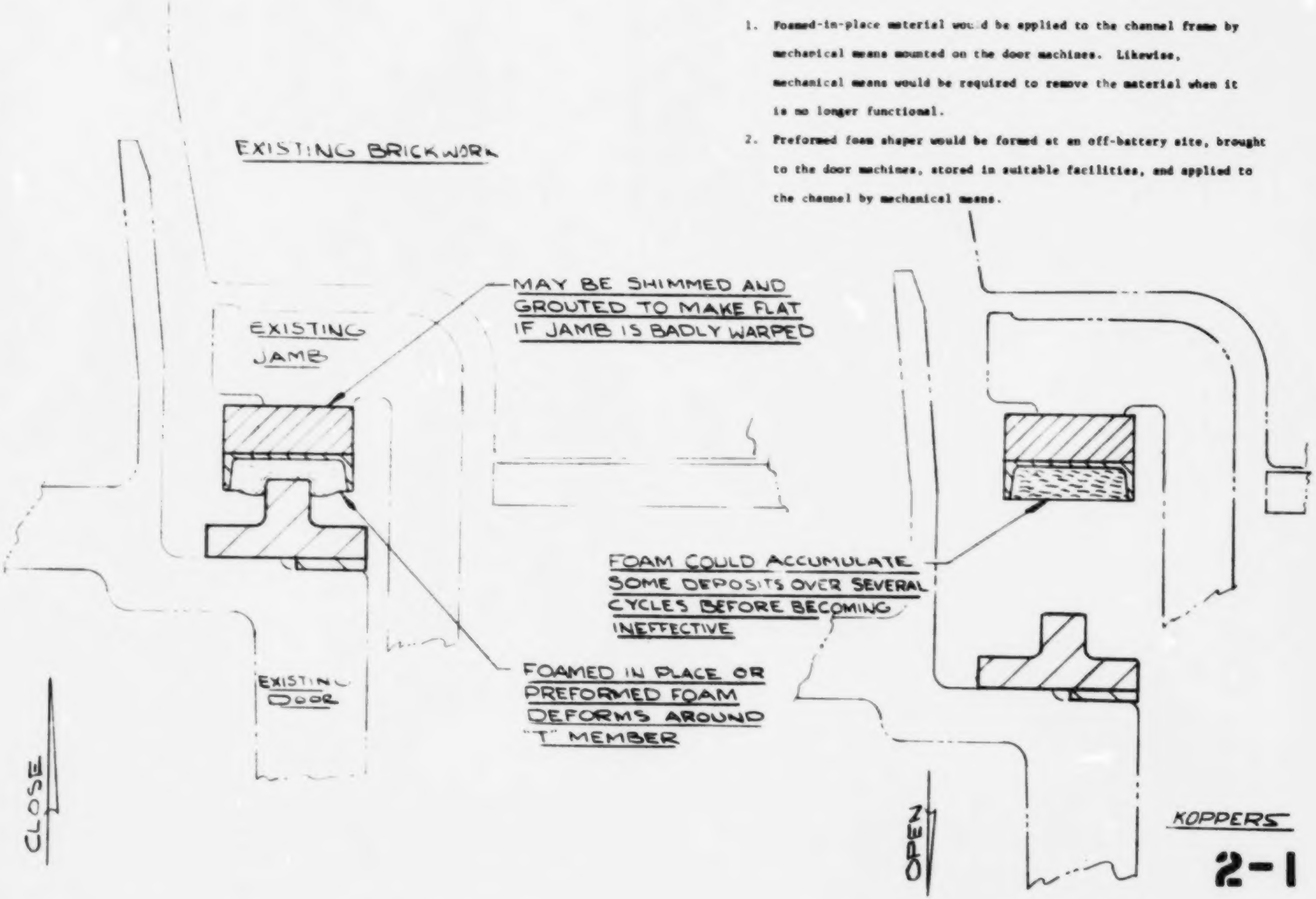
Door Jambs. Existing door jambs of various designs are compatible with this concept, except that extreme "hourglass" distortion would restrict door placement and removal. The presently acceptable degree of flatness of the jamb is not detrimental to application of the concept.

Seal Components. Existing door seals are not retained in this concept, but are replaced with more rugged components. Surface-to-surface contact of metal components as required in existing knife-edge seals is not required in this concept. However, in the design possibilities shown in Drawings 2-5 and 2-6, surface-to-surface contact could occur at several locations along the jamb.

Oven Doors. Existing doors of various designs are compatible with this concept and, if in good condition, would require only simple modification to accept the new seal component(s).

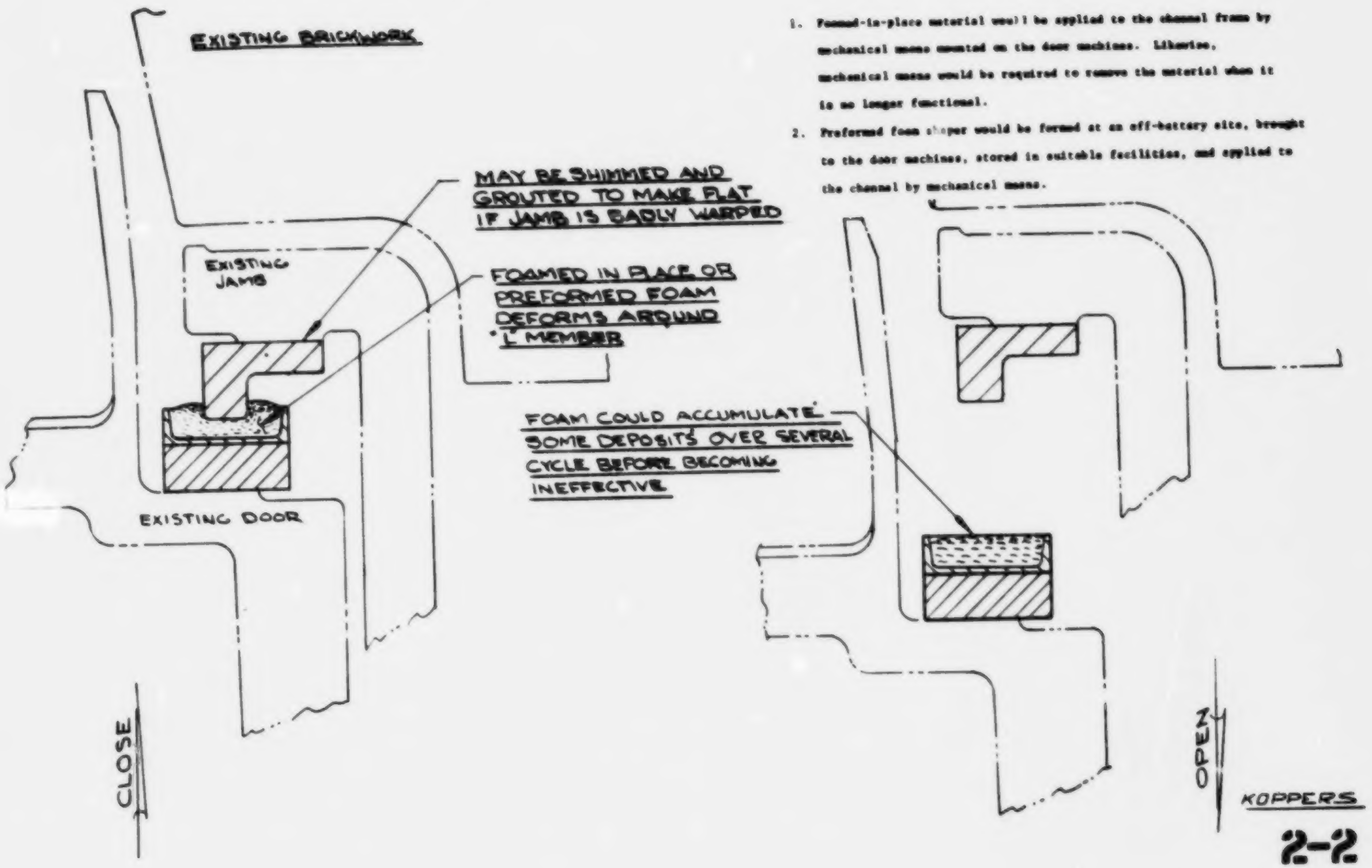
Cleaning. The cleaning required by this concept is minimized by the ability of the sealing media to conform to surface irregularities including those formed by previous deposits of sealing media. Sealing media and other accumulated deposits of the coking process which would cling to the door, the jamb, and the sealing components in excessive amounts would be cleaned periodically by conventional mechanized scraping.

1. Foamed-in-place material would be applied to the channel frame by mechanical means mounted on the door machines. Likewise, mechanical means would be required to remove the material when it is no longer functional.
2. Preformed foam shaper would be formed at an off-battery site, brought to the door machines, stored in suitable facilities, and applied to the channel by mechanical means.

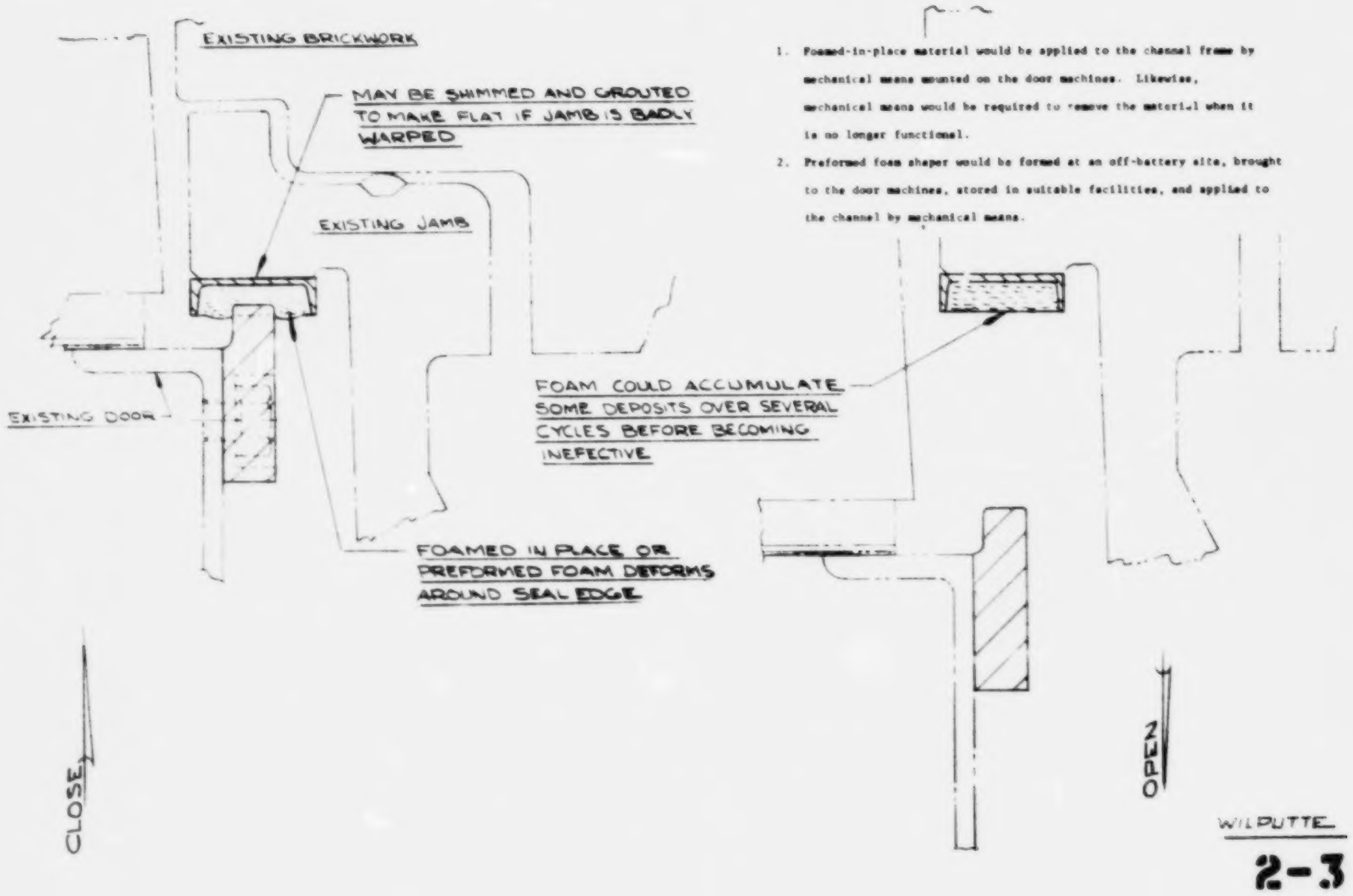

EXISTING BRICKWORK
EXISTING JAMB
MAY BE SHIMMED AND GROUTED TO MAKE FLAT IF JAMB IS BADLY WARPED
FOAMED IN PLACE OR PREFORMED FOAM DEFORMS AROUND "T" MEMBER
EXISTING DOOR
CLOSE
FOAM COULD ACCUMULATE SOME DEPOSITS OVER SEVERAL CYCLES BEFORE BECOMING INEFFECTIVE
OPEN

KOPPERS

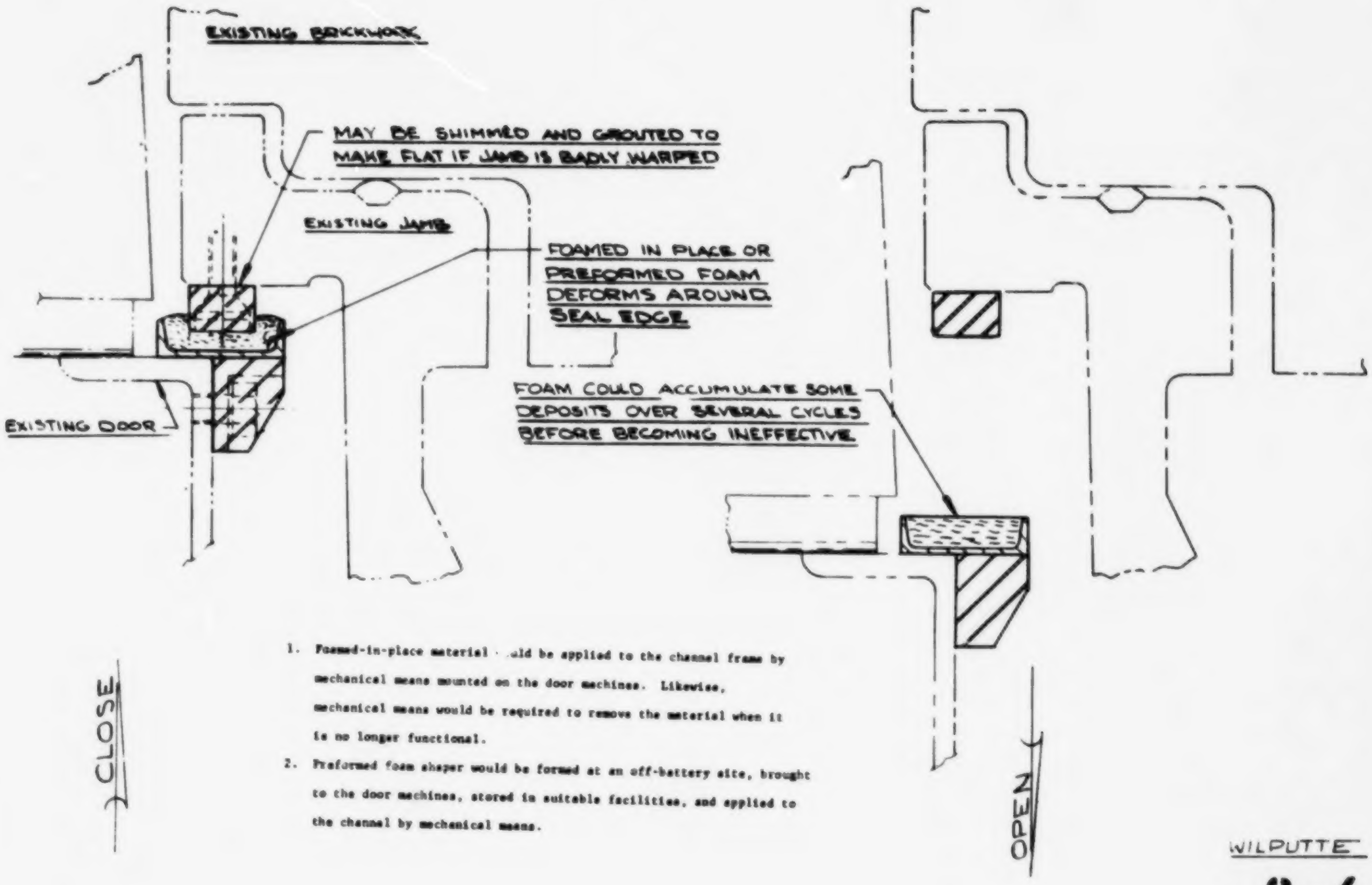
2-1


EXISTING BRICKWORK
MAY BE SHIMMED AND GROUTED TO MAKE FLAT IF JAMB IS BADLY WARPED
EXISTING JAMB
FOAMED IN PLACE OR PREFORMED FOAM DEFORMS AROUND "L" MEMBER
EXISTING DOOR
FOAM COULD ACCUMULATE SOME DEPOSITS OVER SEVERAL CYCLE BEFORE BECOMING INEFFECTIVE
CLOSE
OPEN
KOPPERS
2-2

1. Foamed-in-place material would be applied to the channel frame by mechanical means mounted on the door machines. Likewise, mechanical means would be required to remove the material when it is no longer functional.
2. Preformed foam shapes would be formed at an off-battery site, brought to the door machines, stored in suitable facilities, and applied to the channel by mechanical means.


EXISTING BRICKWORK
MAY BE SHIMMED AND GROUTED TO MAKE FLAT IF JAMB IS BADLY WARPED
EXISTING JAMB
EXISTING DOOR
FOAMED IN PLACE OR PREFORMED FOAM DEFORMS AROUND SEAL EDGE
FOAM COULD ACCUMULATE SOME DEPOSITS OVER SEVERAL CYCLES BEFORE BECOMING INEFECTIVE
CLOSE
OPEN
WILPUTTE
2-3

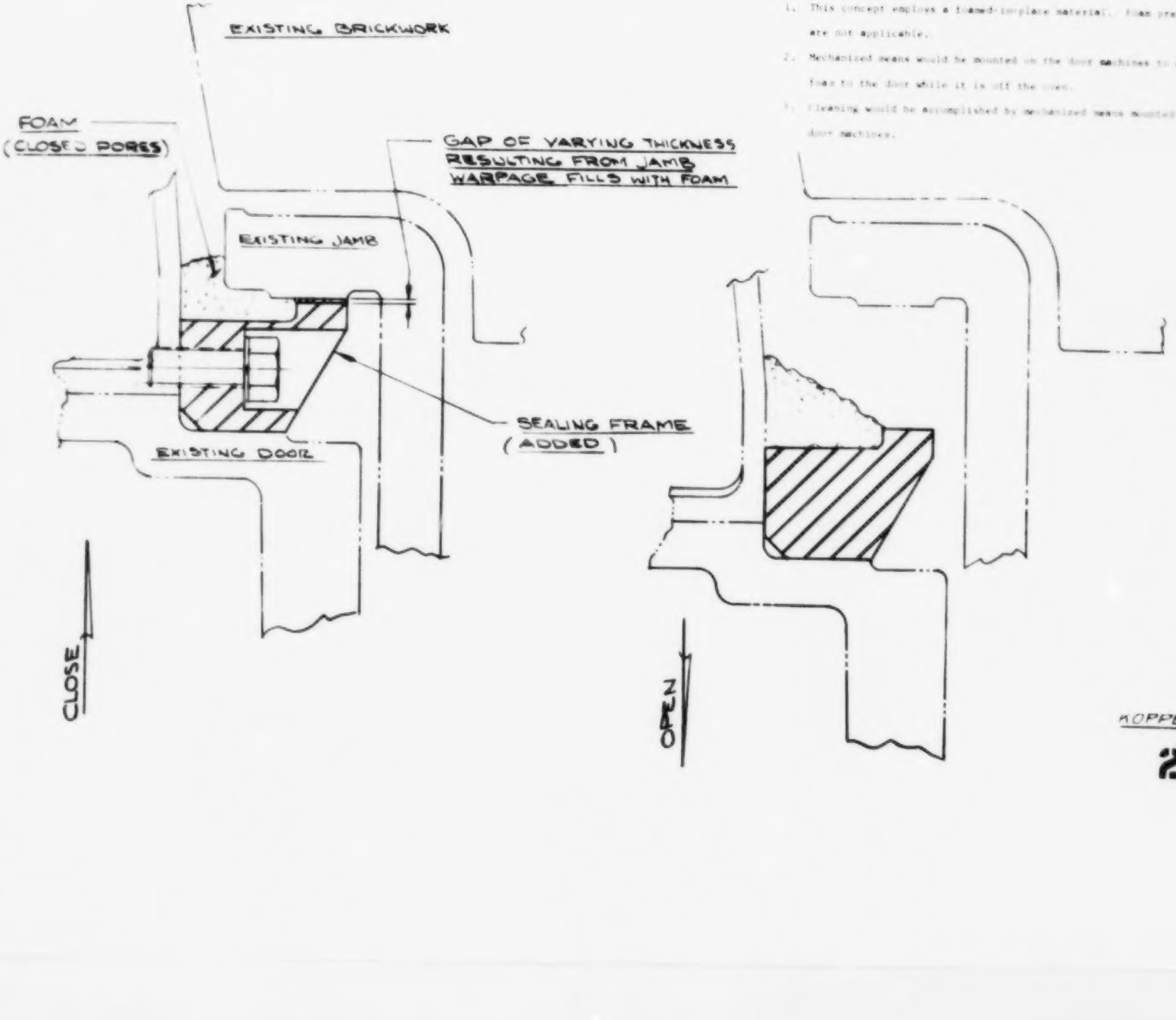
1. Foamed-in-place material would be applied to the channel frame by mechanical means mounted on the door machines. Likewise, mechanical means would be required to remove the material when it is no longer functional.
2. Preformed foam shaper would be formed at an off-battery site, brought to the door machines, stored in suitable facilities, and applied to the channel by mechanical means.


EXISTING BRICKWORK
MAY BE SHIMMED AND GROUTED TO MAKE FLAT IF JAMB IS BADLY WARPED
EXISTING JAMB
FOAMED IN PLACE OR PREFORMED FOAM DEFORMS AROUND SEAL EDGE
EXISTING DOOR
FOAM COULD ACCUMULATE SOME DEPOSITS OVER SEVERAL CYCLES BEFORE BECOMING INEFFECTIVE
CLOSE
OPEN

1. Foamed-in-place material could be applied to the channel frame by mechanical means mounted on the door machines. Likewise, mechanical means would be required to remove the material when it is no longer functional.
2. Preformed foam shaper would be formed at an off-battery site, brought to the door machines, stored in suitable facilities, and applied to the channel by mechanical means.

WILPUTTE

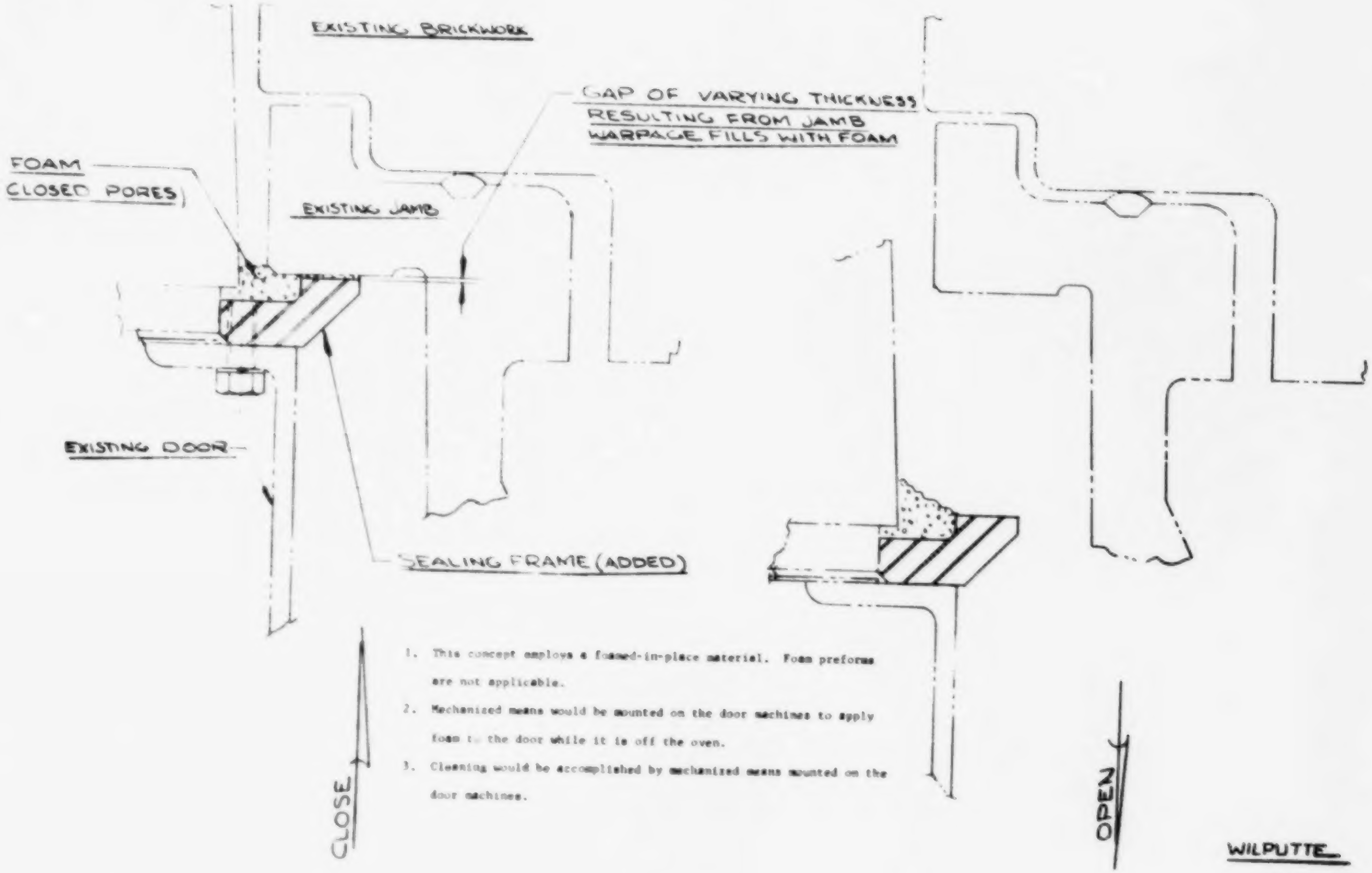
2-4



1. This concept employs a foamed-in-place material. Foam preforms are not applicable.
2. Mechanized means would be mounted on the door machines to apply foam to the door while it is off the oven.
3. Cleaning would be accomplished by mechanized means mounted on the door machines.

KOPPERS

2-5



1. This concept employs a foamed-in-place material. Foam preforms are not applicable.
2. Mechanized means would be mounted on the door machines to apply foam to the door while it is off the oven.
3. Cleaning would be accomplished by mechanized means mounted on the door machines.

WILPUTTE

2-6

Seal Concept Family 3 - Resilient Seals

This concept involves seals located in the conventional zone of existing knife-edge seals. The intent is to use continuous shapes of resilient materials mounted to the door or jamb. These shapes are fabricated and molded of various materials in a variety of cross-sectional designs to form a seal with mating surfaces which may be somewhat irregular. Similar devices for many industrial applications are commercially available from many standard as well as custom designs. Some available materials and some new materials under development possess properties which could be suitable for this application.

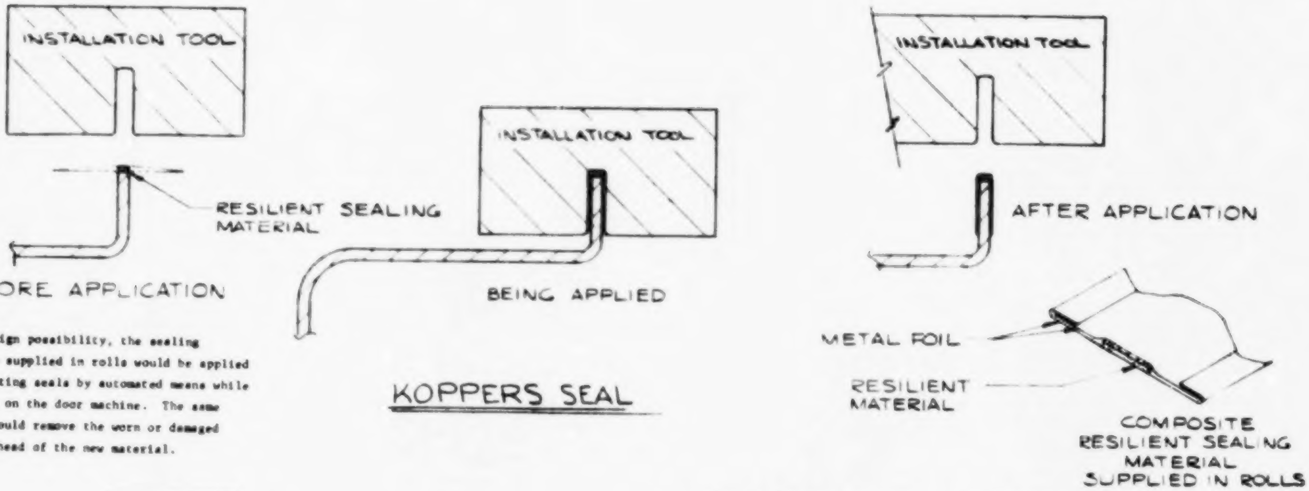
Several design possibilities illustrating this concept are shown in Drawings 3-1 through 3-11. The following discussion of the concept refers to these drawings and reveals relationships between the concept and conventional designs of ovens and operating equipment.

Door Jambs. Existing door jambs of various designs are compatible with this concept, except as follows:

(1) Extreme "hourglass" distortion would restrict door placement and removal.

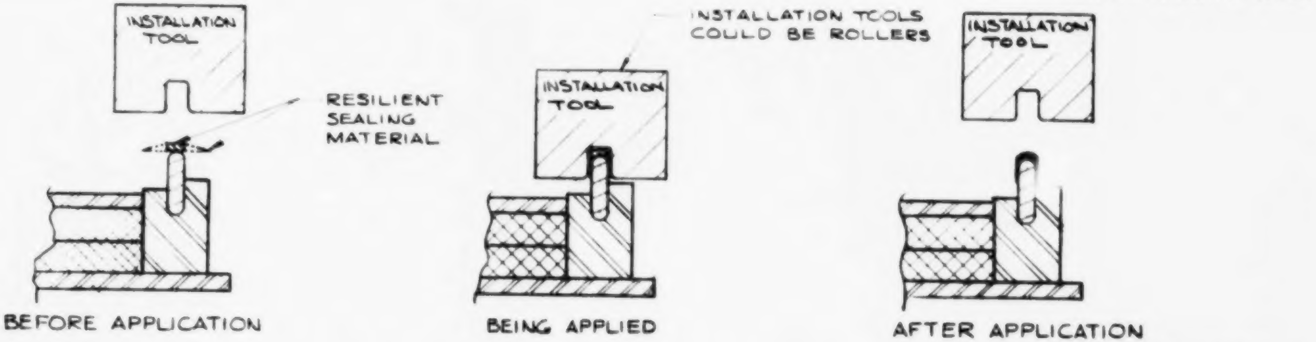
(2) If a seal component is to be added to the jamb (see Drawings 3-7 and 3-8), this component could be shimmed and grouted to re-establish flatness of a warped jamb. Presently acceptable degree of flatness of the jamb is not detrimental if no seal component is to be added to the jamb. The resilient seal could conform to a warped jamb.

Seal Components. Existing door seals of various designs could be compatible with this concept and could be retained as a secondary sealing mechanism. However, existing seals would be replaced with similar features which would provide secondary sealing as well as protection for elastomeric seals. The resilient seal would require protection from (1) radiant as well as conductive heat, (2) mechanical damage, (3) oven-gas chemicals, and (4) contact with hot coke. Means for accomplishing these requirements are specifically noted in the sketches of design possibilities.



In this design possibility, the sealing material as supplied in rolls would be applied to the existing seals by automated means while the door is on the door machine. The same operation could remove the worn or damaged seal just ahead of the new material.

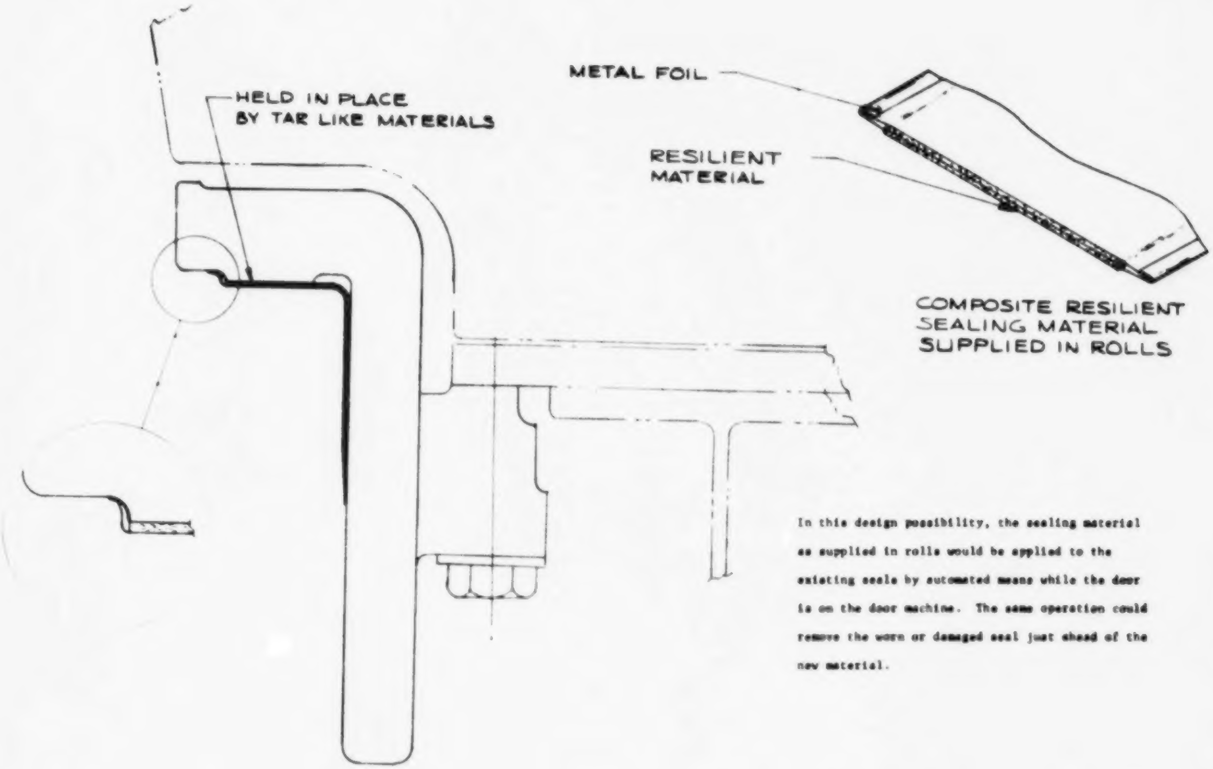
KOPPERS SEAL



WILPUTTE SEAL

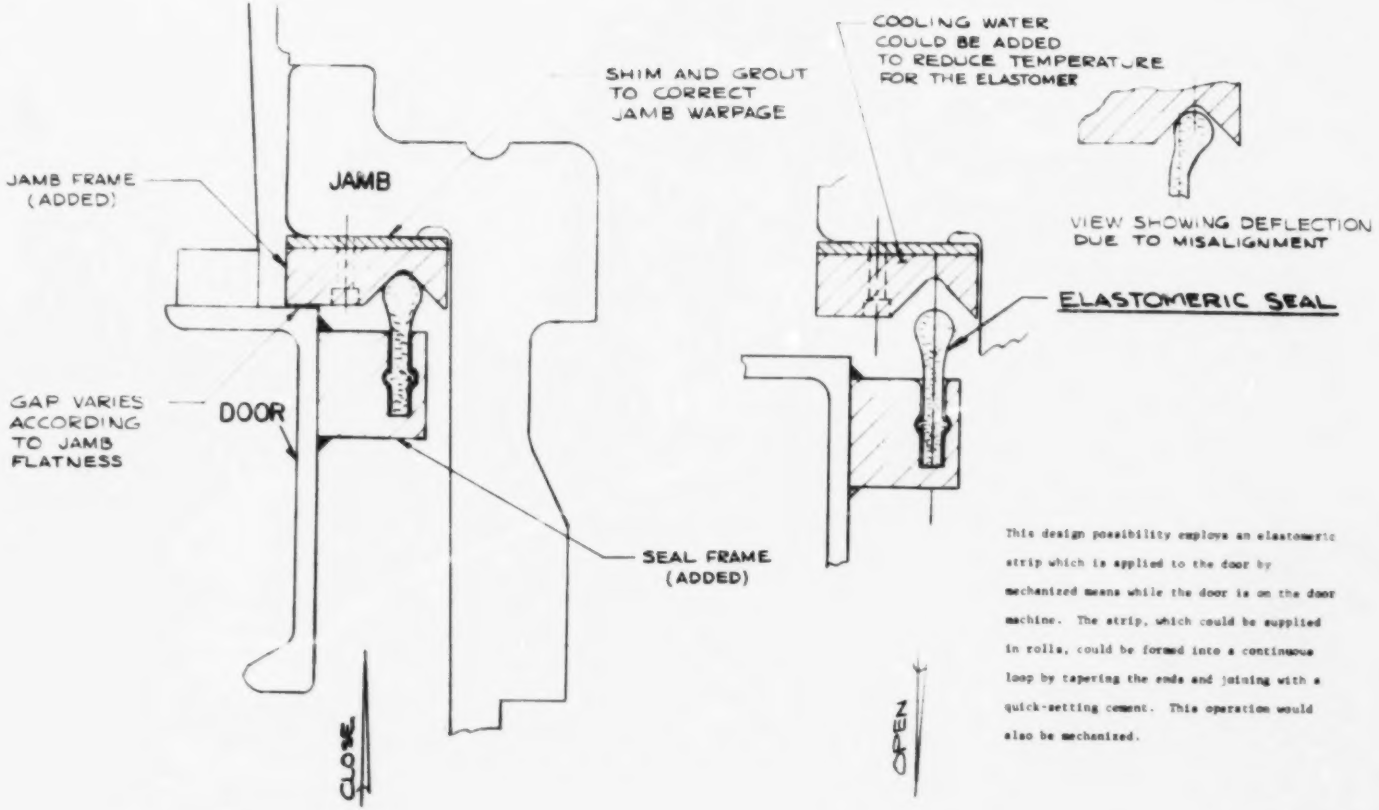
KOPPERS AND WILPUTTE

3-1



In this design possibility, the sealing material as supplied in rolls would be applied to the existing seals by automated means while the door is on the door machine. The same operation could remove the worn or damaged seal just ahead of the new material.

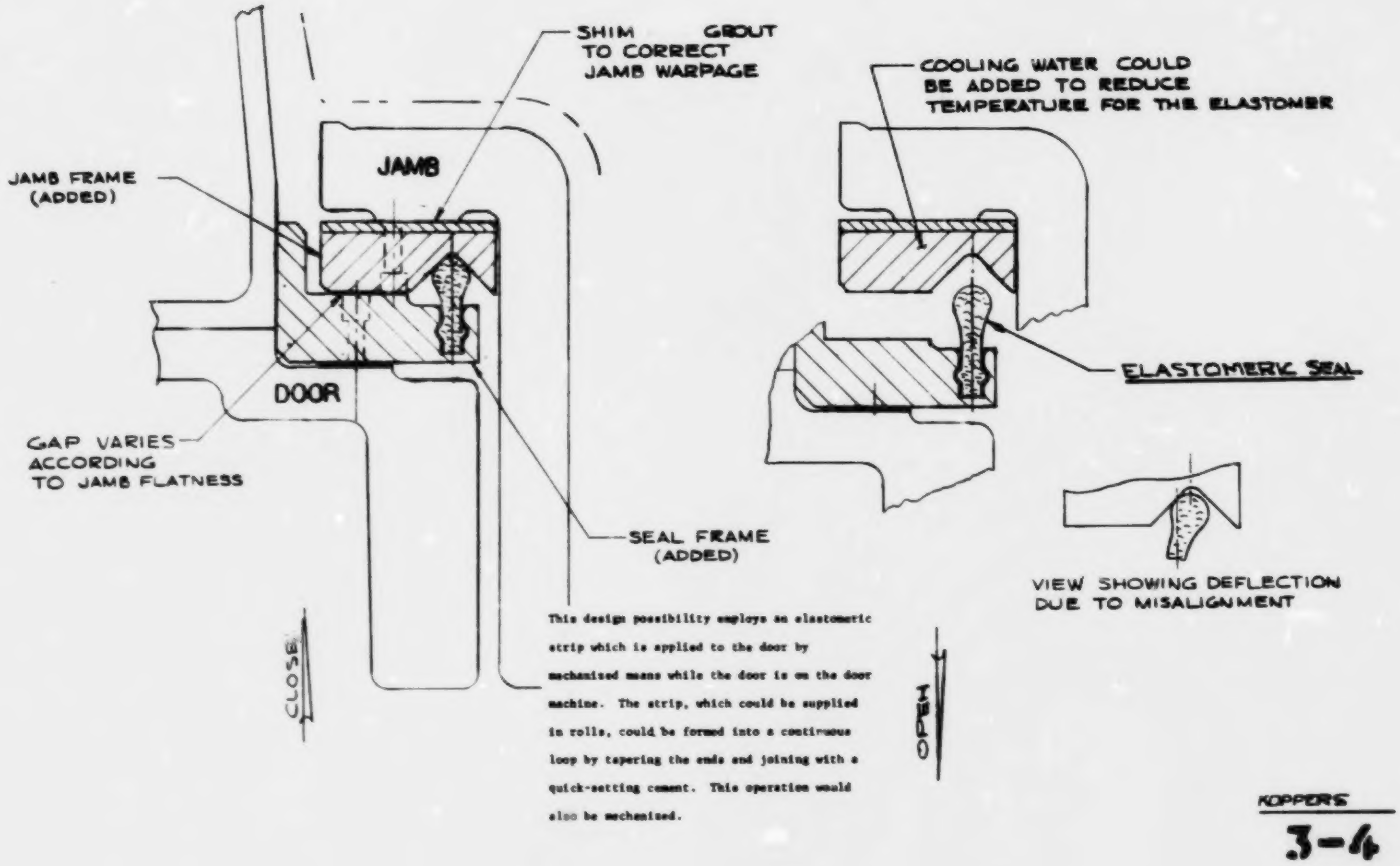
3-2


JAMB FRAME (ADDED)
JAMB
SHIM AND GROUT TO CORRECT JAMB WARPAGE
COOLING WATER COULD BE ADDED TO REDUCE TEMPERATURE FOR THE ELASTOMER
VIEW SHOWING DEFLECTION DUE TO MISALIGNMENT
ELASTOMERIC SEAL
GAP VARIES ACCORDING TO JAMB FLATNESS
DOOR
SEAL FRAME (ADDED)
CLOSE
OPEN

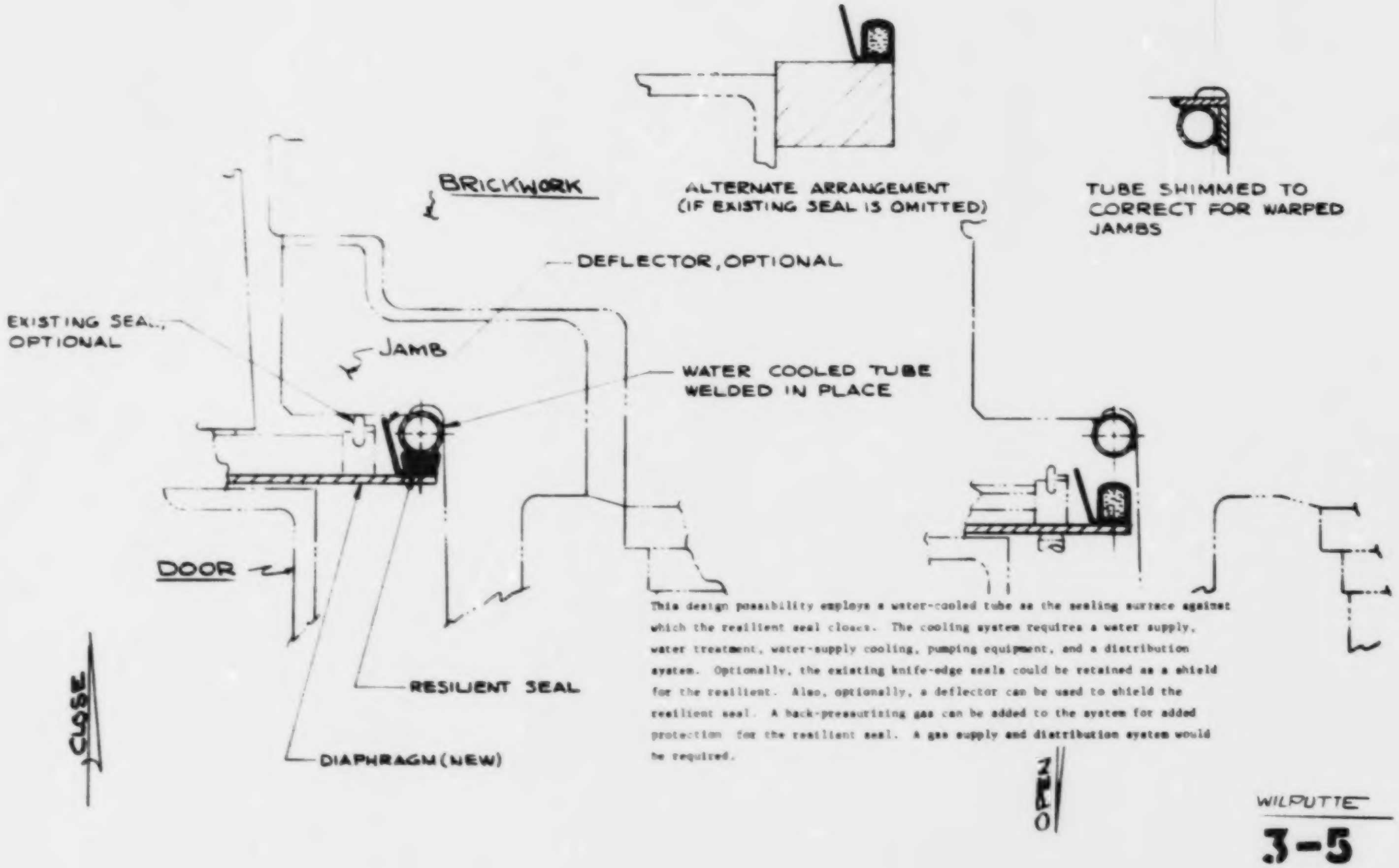
This design possibility employs an elastomeric strip which is applied to the door by mechanized means while the door is on the door machine. The strip, which could be supplied in rolls, could be formed into a continuous loop by tapering the ends and joining with a quick-setting cement. This operation would also be mechanized.

WILPUTTE

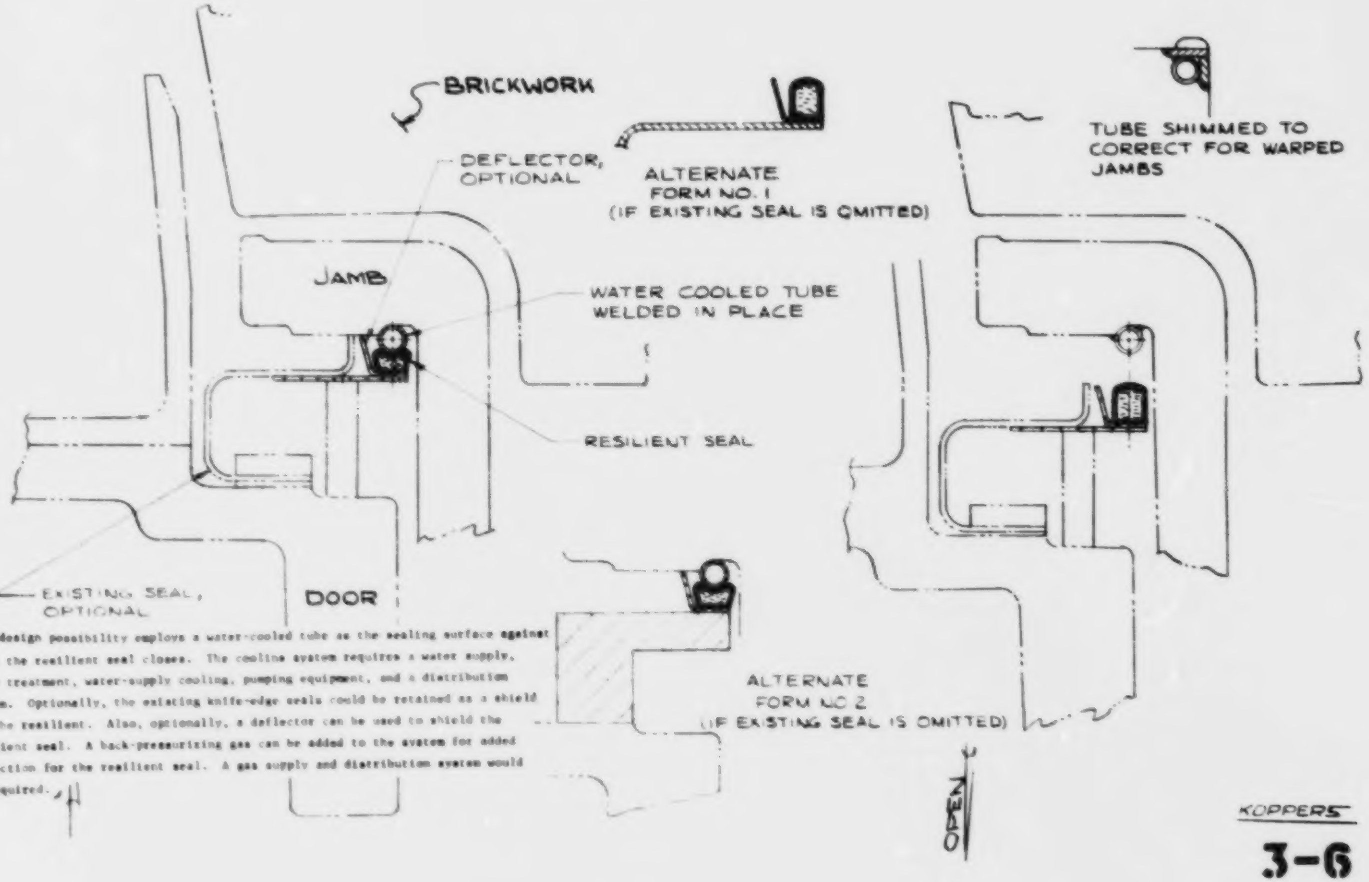
3-3



This design possibility employs an elastomeric strip which is applied to the door by mechanized means while the door is on the door machine. The strip, which could be supplied in rolls, could be formed into a continuous loop by tapering the ends and joining with a quick-setting cement. This operation would also be mechanized.



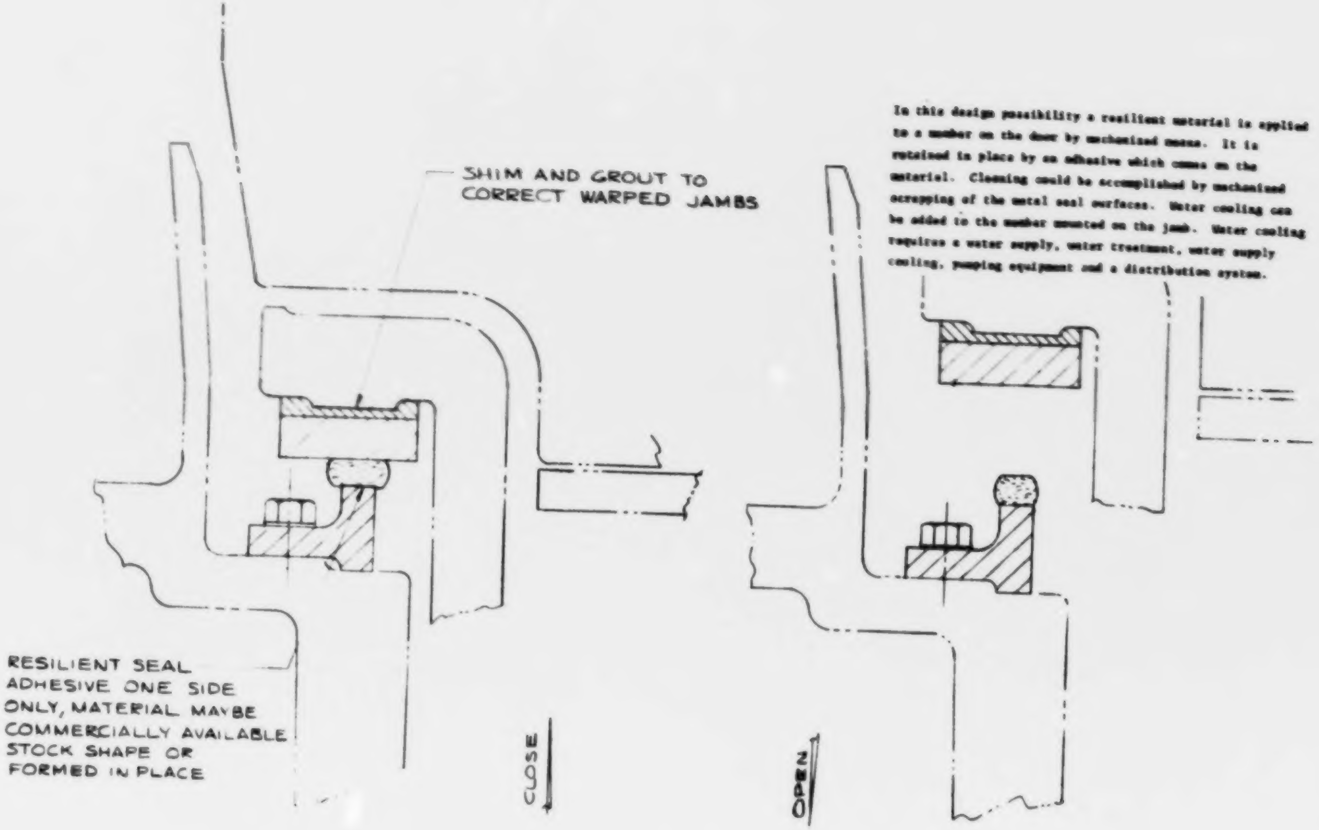
This design possibility employs a water-cooled tube as the sealing surface against which the resilient seal closes. The cooling system requires a water supply, water treatment, water-supply cooling, pumping equipment, and a distribution system. Optionally, the existing knife-edge seals could be retained as a shield for the resilient. Also, optionally, a deflector can be used to shield the resilient seal. A back-pressurizing gas can be added to the system for added protection for the resilient seal. A gas supply and distribution system would be required.


BRICKWORK
DEFLECTOR, OPTIONAL
ALTERNATE FORM NO. 1 (IF EXISTING SEAL IS OMITTED)
TUBE SHIMMED TO CORRECT FOR WARPED JAMBS
JAMB
WATER COOLED TUBE WELDED IN PLACE
RESILIENT SEAL
EXISTING SEAL, OPTIONAL
DOOR
ALTERNATE FORM NO 2 (IF EXISTING SEAL IS OMITTED)
OPEN

This design possibility employs a water-cooled tube as the sealing surface against which the resilient seal closes. The cooling system requires a water supply, water treatment, water-supply cooling, pumping equipment, and a distribution system. Optionally, the existing knife-edge seals could be retained as a shield for the resilient. Also, optionally, a deflector can be used to shield the resilient seal. A back-pressurizing gas can be added to the system for added protection for the resilient seal. A gas supply and distribution system would be required.

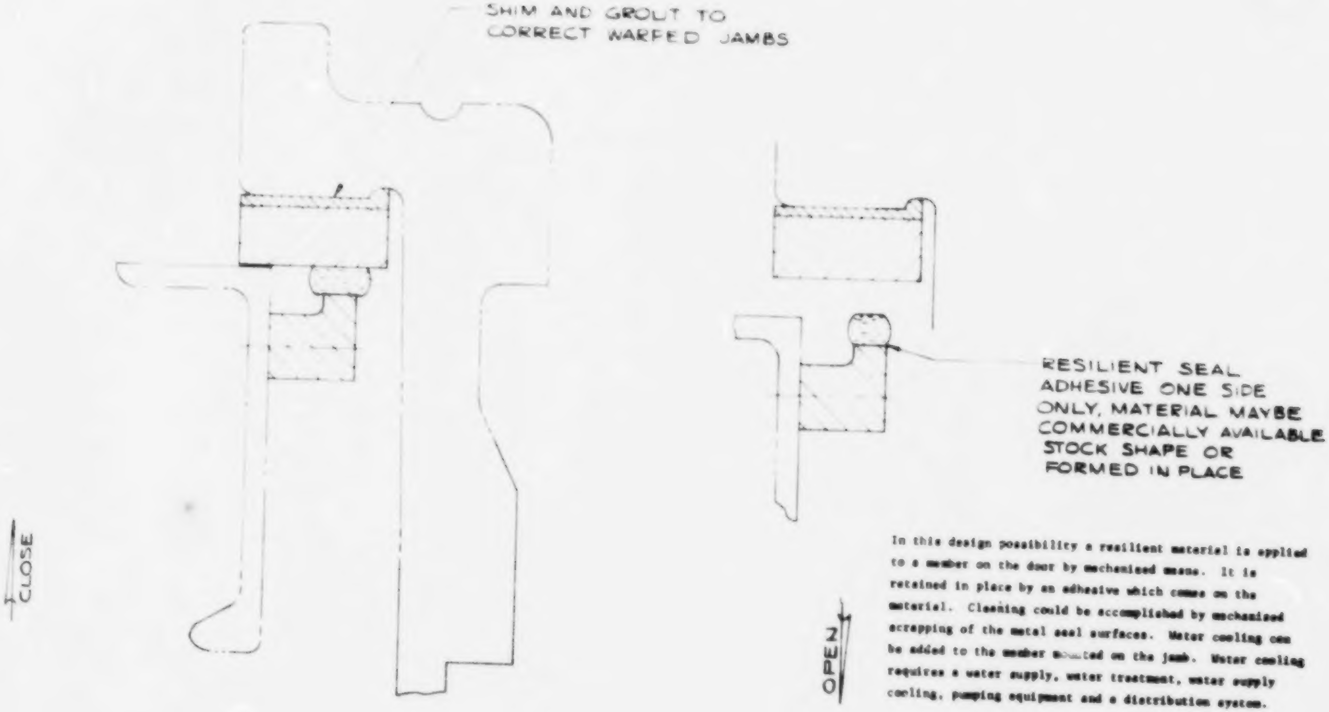
KOPPERS

3-6


SHIM AND GROUT TO CORRECT WARPED JAMBS
RESILIENT SEAL ADHESIVE ONE SIDE ONLY, MATERIAL MAYBE COMMERCIALLY AVAILABLE STOCK SHAPE OR FORMED IN PLACE
CLOSE
OPEN

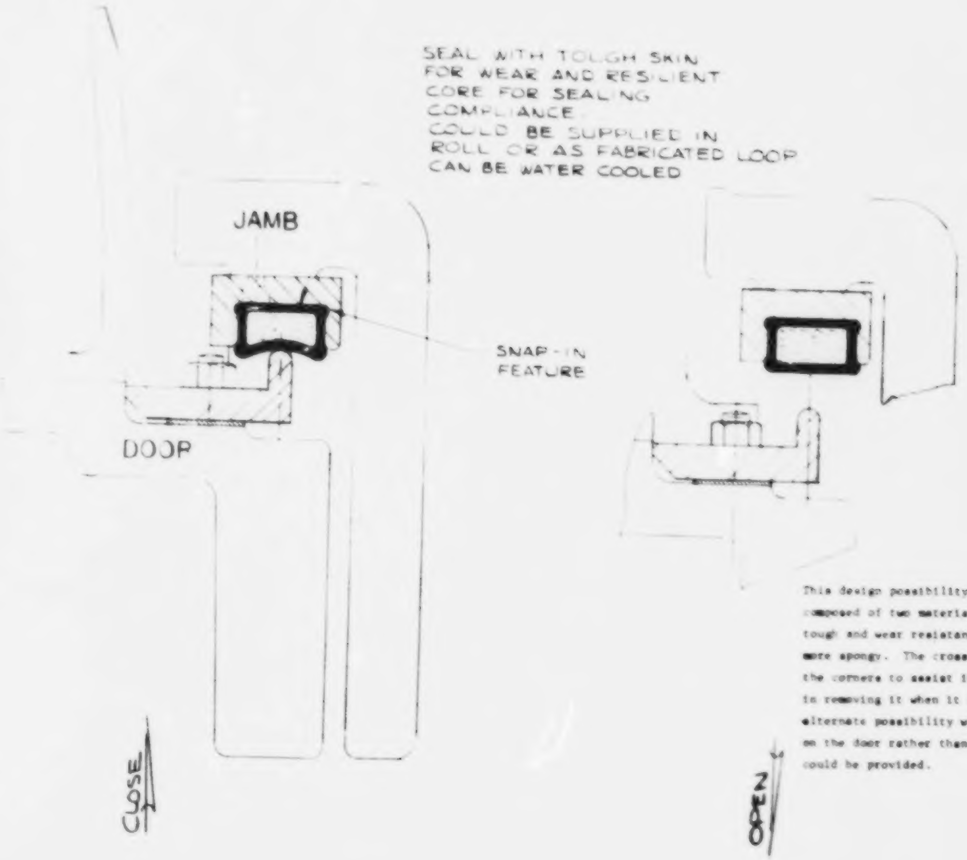
In this design possibility a resilient material is applied to a member on the door by mechanized means. It is retained in place by an adhesive which comes on the material. Cleaning could be accomplished by mechanized scrapping of the metal seal surfaces. Water cooling can be added to the member mounted on the jamb. Water cooling requires a water supply, water treatment, water supply cooling, pumping equipment and a distribution system.

KOPPERS
3-7



In this design possibility a resilient material is applied to a member on the door by mechanized means. It is retained in place by an adhesive which comes on the material. Cleaning could be accomplished by mechanized scrapping of the metal seal surfaces. Water cooling can be added to the member mounted on the jamb. Water cooling requires a water supply, water treatment, water supply cooling, pumping equipment and a distribution system.

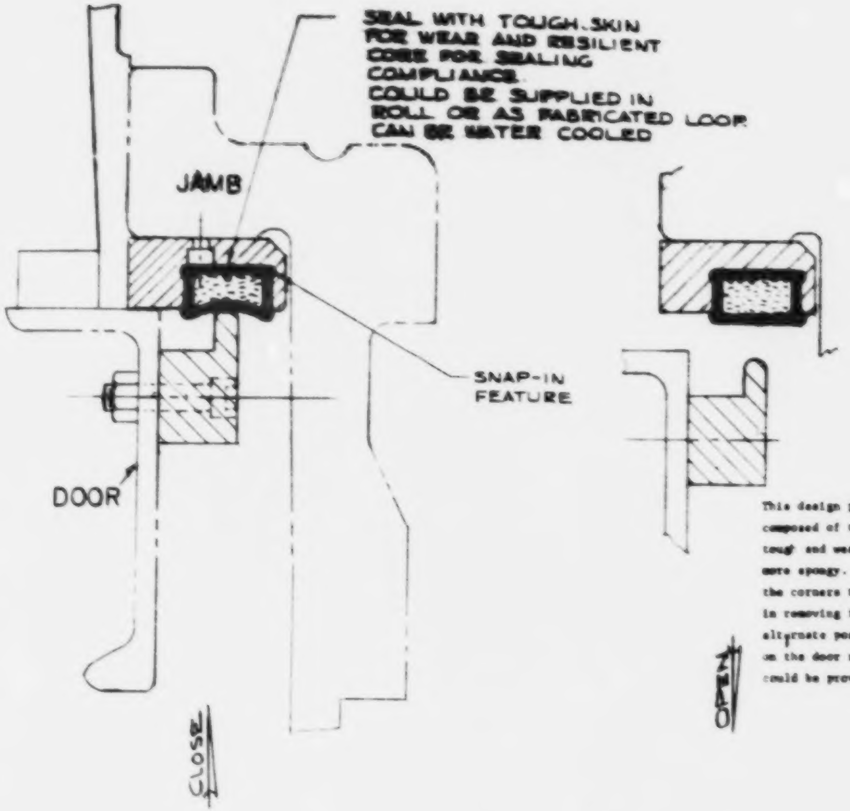
WILPUTTE
3-8



This design possibility uses a resilient component composed of two materials. The outer material is tough and wear resistant while the inner material is more spongy. The cross-section form has bulbs at the corners to assist in retaining the seal and also in removing it when it needs to be replaced. An alternate possibility would mount the resilient seal on the door rather than on the jamb. Water cooling could be provided.

KOPPERS

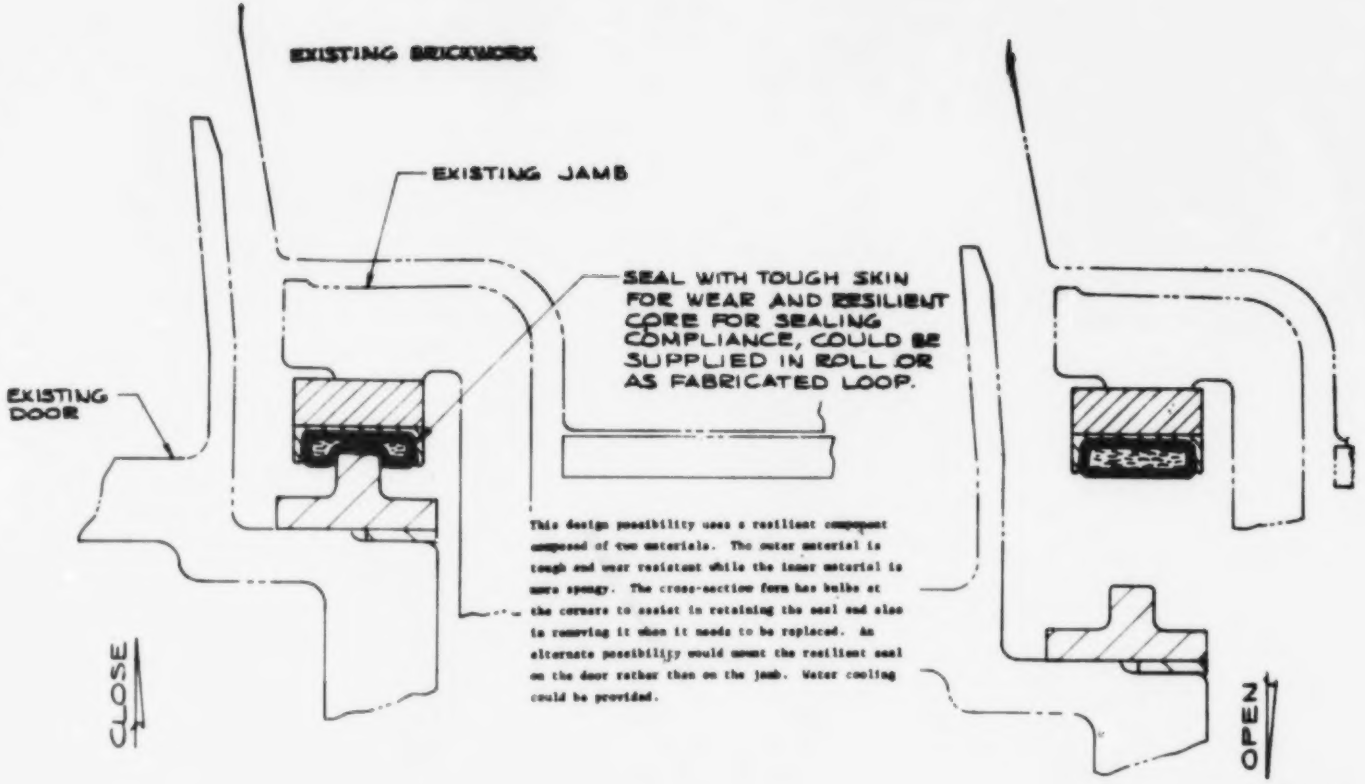
3-9



This design possibility uses a resilient component composed of two materials. The outer material is tough and wear resistant while the inner material is more spongy. The cross-section form has bulbs at the corners to assist in retaining the seal and also in removing it when it needs to be replaced. An alternate possibility would mount the resilient seal on the door rather than on the jamb. Water cooling could be provided.

WILPUTTE

3-10


EXISTING BRICKWORK
EXISTING JAMB
SEAL WITH TOUGH SKIN FOR WEAR AND RESILIENT CORE FOR SEALING COMPLIANCE, COULD BE SUPPLIED IN ROLL OR AS FABRICATED LOOP.
EXISTING DOOR
CLOSE
OPEN

This design possibility uses a resilient component composed of two materials. The outer material is tough and wear resistant while the inner material is more spongy. The cross-section form has bulbs at the corners to assist in retaining the seal and also in removing it when it needs to be replaced. An alternate possibility would mount the resilient seal on the door rather than on the jamb. Water cooling could be provided.

3-11

Oven Doors. Existing doors of various designs are compatible with this concept and would be retained with slight modifications such as:

(1) Elimination of existing seal components and plugging of any resulting openings.

(2) Addition of new seal components by bolting or welding.

(3) Addition of holes for injection of back-pressurizing gas.

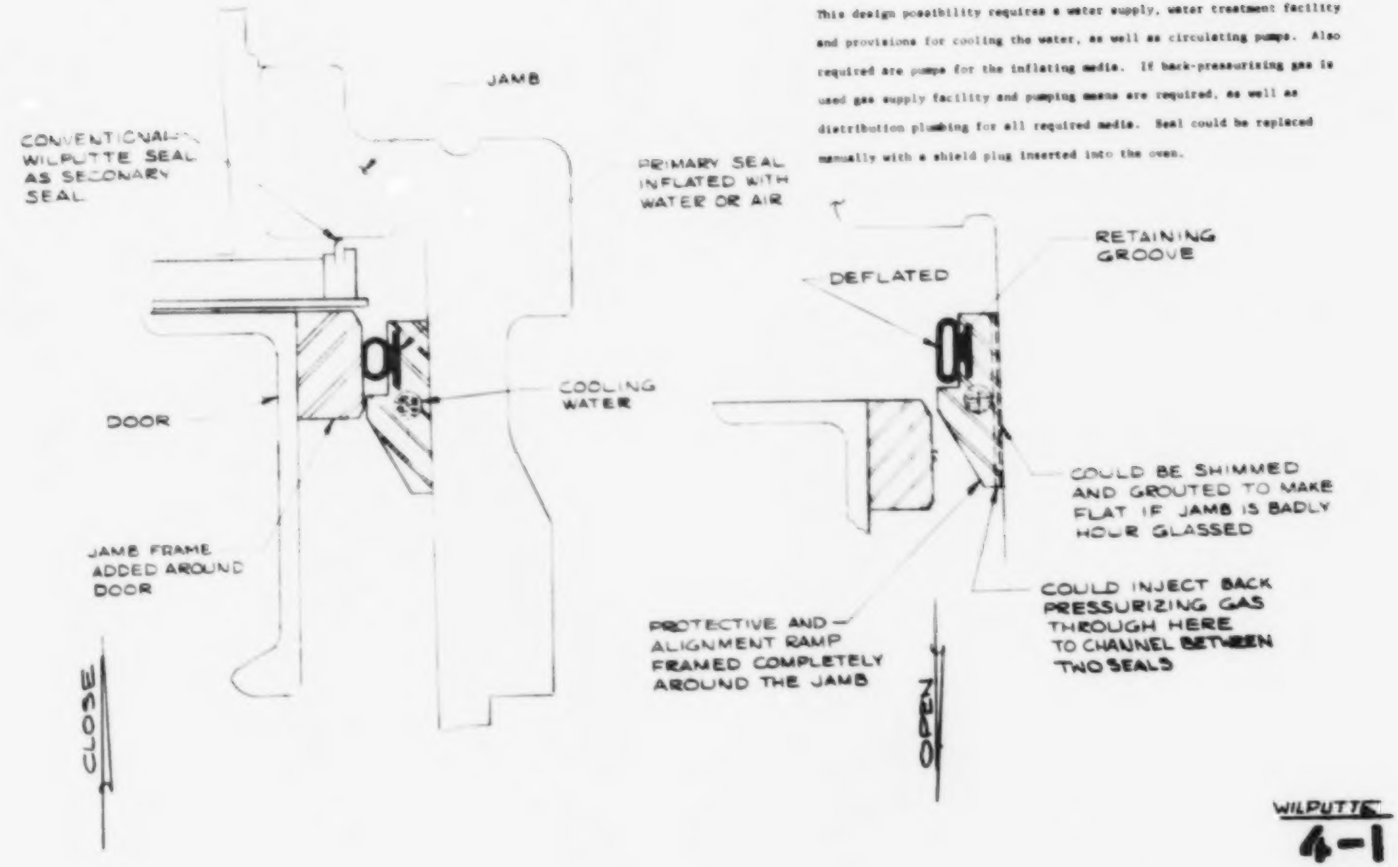
Cleaning. Cleaning required by this concept would be accomplished by scraper mechanisms mounted on the door machine if metal seal areas are to be cleaned. However, if the resilient seal material should require cleaning, automated, high-pressure water jets might be utilized for both door and jamb areas, on both metal surfaces and the resilient seal material. Cleaning would be minimized by inboard, secondary-seal features which would exclude gross intrustion of particulates.

Seal Concept Family 4 - Inflatable Seals

This concept includes inflatable seals located in the cold zone or the conventional sealing area relative to the door and jamb. The intent of this concept is to utilize continuous frame shapes of elastomeric tubes, mounted to the door or jamb, and which may be inflated to form a seal. These frame shapes are fabricated and molded of various materials and in a variety of cross-sectional designs so that, when inflated, the cross section is extensible (as an accordion) to form a seal with mating surfaces which may be somewhat irregular. Similar devices for many industrial applications are commercially available with standard as well as custom designs. Some available materials may possess properties which could be suitable for this application. Liquids or gases could be used for inflating the seal.

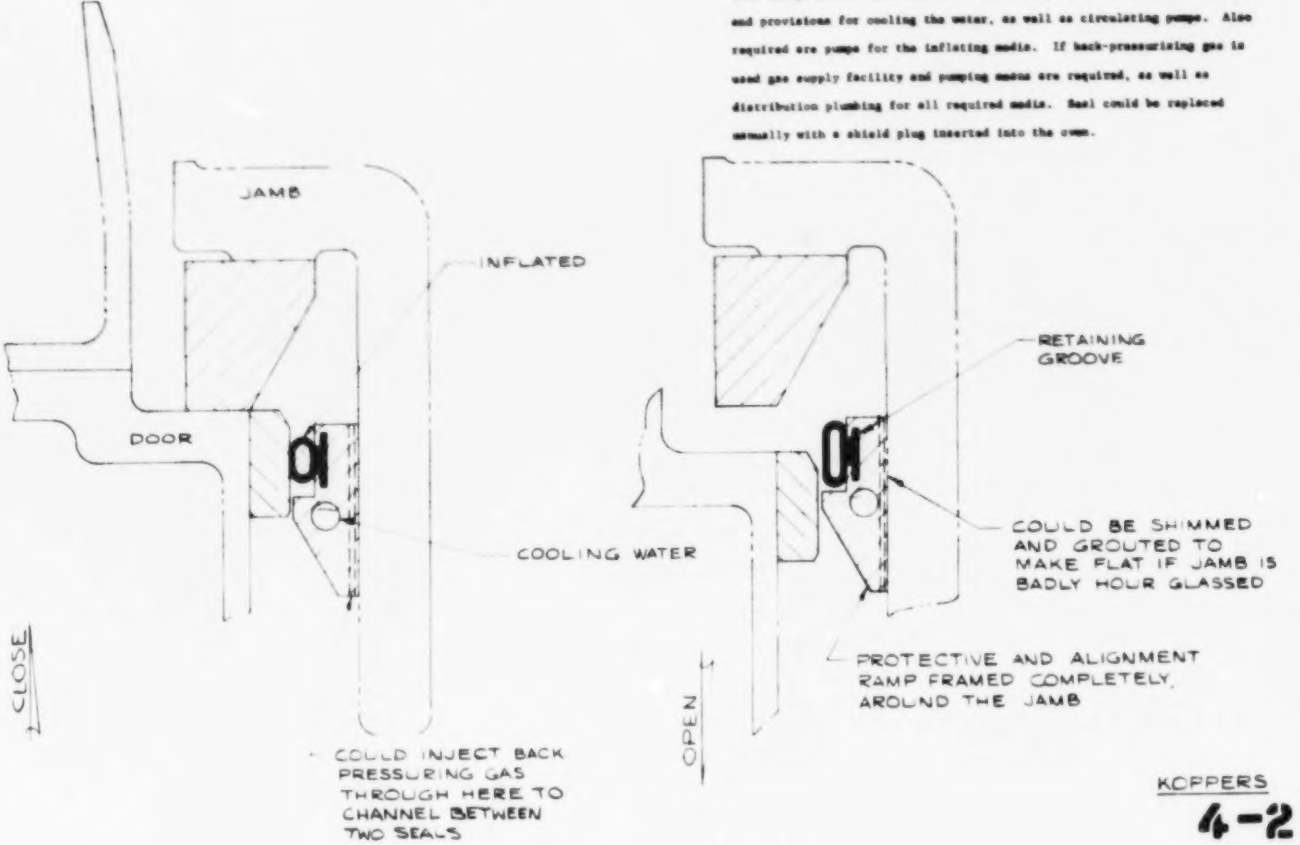
Several design possibilities illustrating this concept are shown in Drawings 4-1 through 4-8. The following discussion of the concept refers to these illustrations and reveals relationships between the concept and conventional designs of ovens and operating equipment.

This design possibility requires a water supply, water treatment facility and provisions for cooling the water, as well as circulating pumps. Also required are pumps for the inflating media. If back-pressurizing gas is used gas supply facility and pumping means are required, as well as distribution plumbing for all required media. Seal could be replaced manually with a shield plug inserted into the oven.


JAMB
CONVENTIONAL WILPUTTE SEAL AS SECONARY SEAL
DOOR
COOLING WATER
JAMB FRAME ADDED AROUND DOOR
CLOSE
PRIMARY SEAL INFLATED WITH WATER OR AIR
DEFLATED
RETAINING GROOVE
COULD BE SHIMMED AND GROUTED TO MAKE FLAT IF JAMB IS BADLY HOUR GLASSED
COULD INJECT BACK PRESSURIZING GAS THROUGH HERE TO CHANNEL BETWEEN TWO SEALS
PROTECTIVE AND ALIGNMENT RAMP FRAMED COMPLETELY AROUND THE JAMB
OPEN

WILPUTTE
4-1

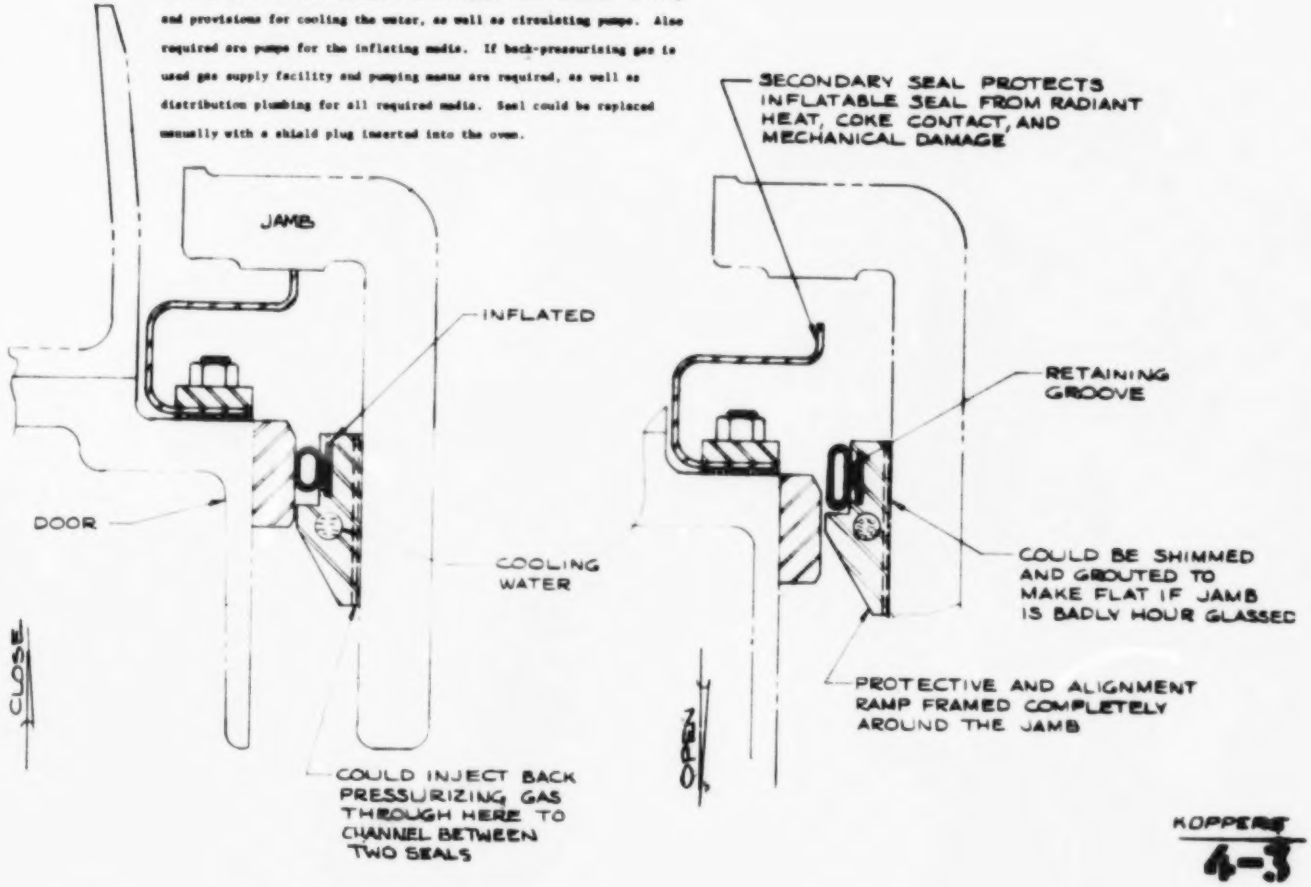
This design possibility requires a water supply, water treatment facility and provisions for cooling the water, as well as circulating pumps. Also required are pumps for the inflating media. If back-pressurizing gas is used gas supply facility and pumping means are required, as well as distribution plumbing for all required media. Seal could be replaced manually with a shield plug inserted into the oven.

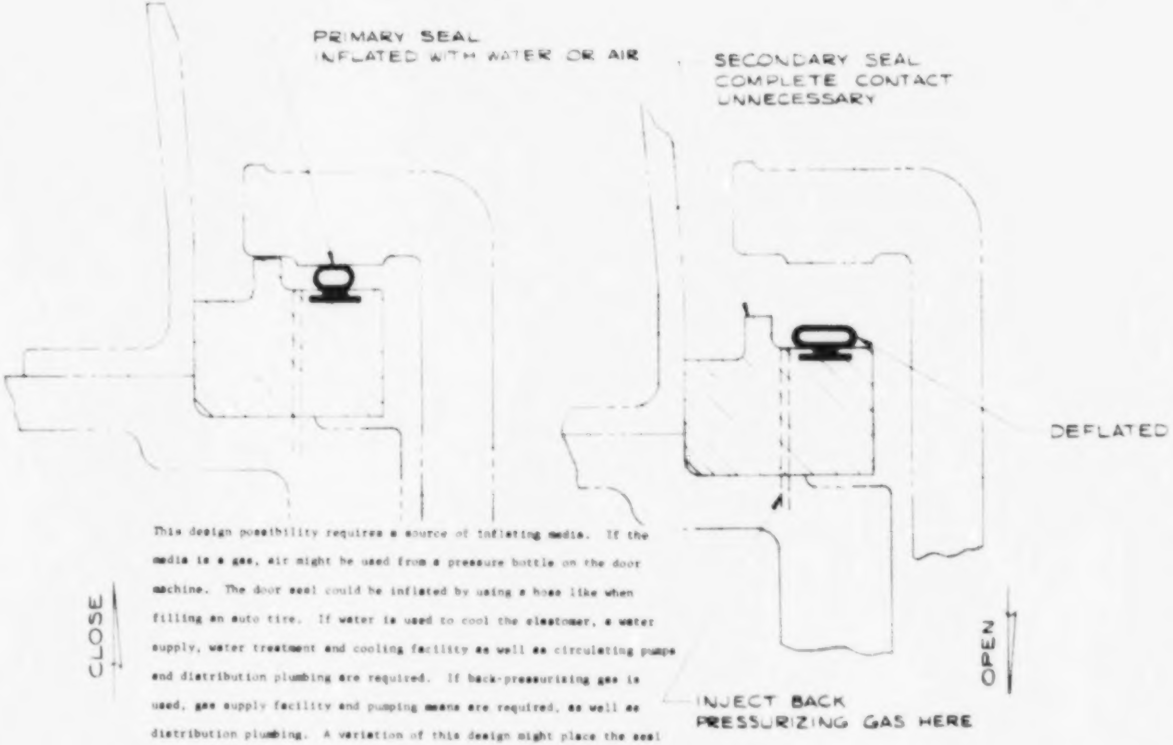

JAMB
INFLATED
DOOR
COOLING WATER
CLOSE
COULD INJECT BACK PRESSURING GAS THROUGH HERE TO CHANNEL BETWEEN TWO SEALS
OPEN
RETAINING GROOVE
COULD BE SHIMMED AND GROUTED TO MAKE FLAT IF JAMB IS BADLY HOUR GLASSED
PROTECTIVE AND ALIGNMENT RAMP FRAMED COMPLETELY AROUND THE JAMB

KOPPERS

4-2

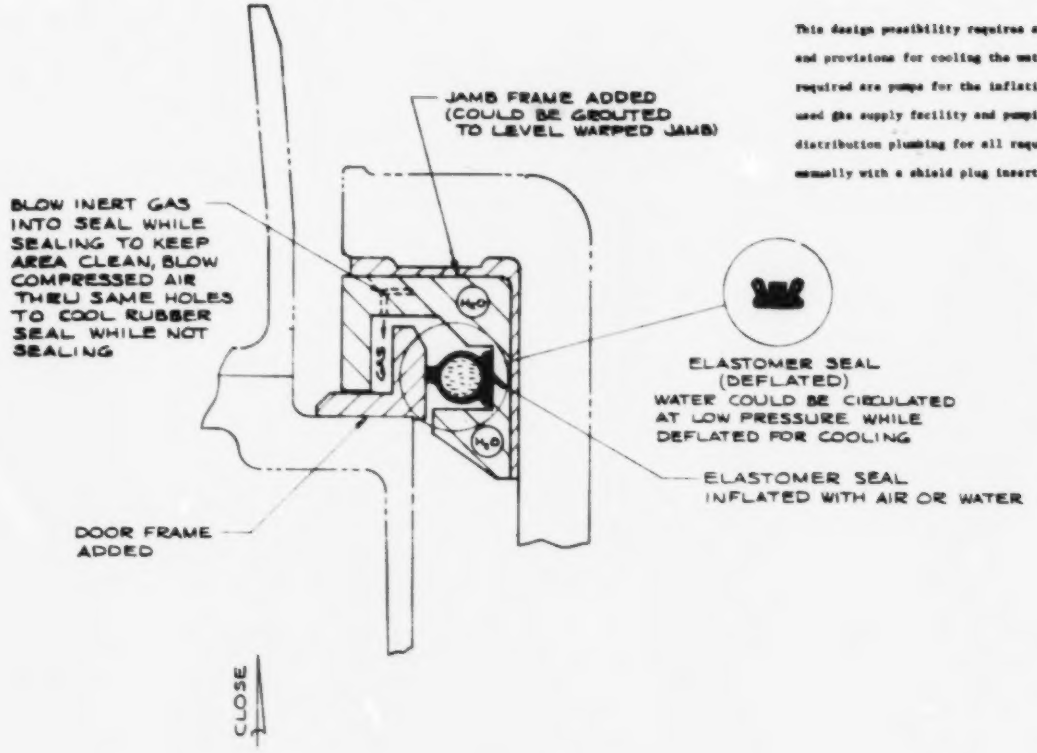
This design possibility requires a water supply, water treatment facility and provisions for cooling the water, as well as circulating pumps. Also required are pumps for the inflating media. If back-pressurizing gas is used gas supply facility and pumping means are required, as well as distribution plumbing for all required media. Seal could be replaced manually with a shield plug inserted into the oven.


JAMB
INFLATED
DOOR
COOLING WATER
CLOSE
COULD INJECT BACK PRESSURIZING GAS THROUGH HERE TO CHANNEL BETWEEN TWO SEALS
SECONDARY SEAL PROTECTS INFLATABLE SEAL FROM RADIANT HEAT, COKE CONTACT, AND MECHANICAL DAMAGE
RETAINING GROOVE
COULD BE SHIMMED AND GROUTED TO MAKE FLAT IF JAMB IS BADLY HOUR GLASSED
PROTECTIVE AND ALIGNMENT RAMP FRAMED COMPLETELY AROUND THE JAMB
OPEN
KOPPERS
4-3



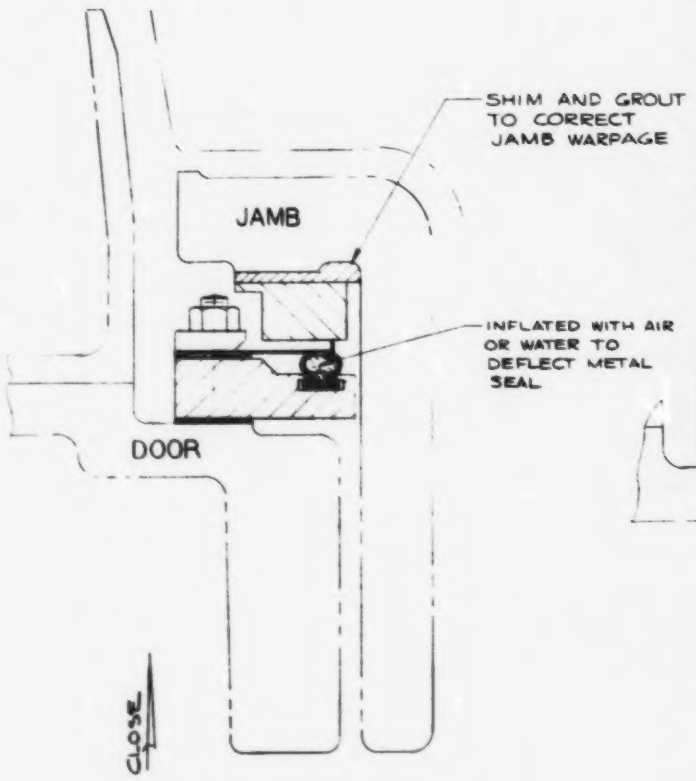
This design possibility requires a source of inflating media. If the media is a gas, air might be used from a pressure bottle on the door machine. The door seal could be inflated by using a hose like when filling an auto tire. If water is used to cool the elastomer, a water supply, water treatment and cooling facility as well as circulating pumps and distribution plumbing are required. If back-pressurizing gas is used, gas supply facility and pumping means are required, as well as distribution plumbing. A variation of this design might place the seal components on the jamb rather than on the door. The seal could be replaced manually when door is on the door machine.

KOPPERS
4-4

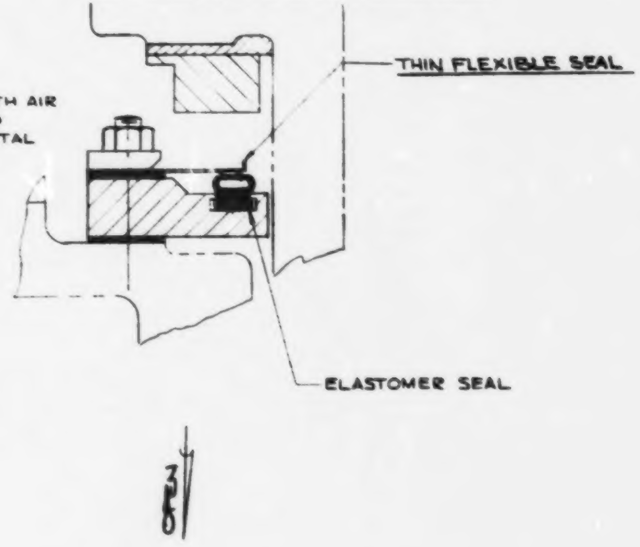


This design possibility requires a water supply, water treatment facility and provisions for cooling the water, as well as circulating pumps. Also required are pumps for the inflating media. If back-pressurizing gas is used gas supply facility and pumping means are required, as well as distribution plumbing for all required media. Seal could be replaced manually with a shield plug inserted into the oven.

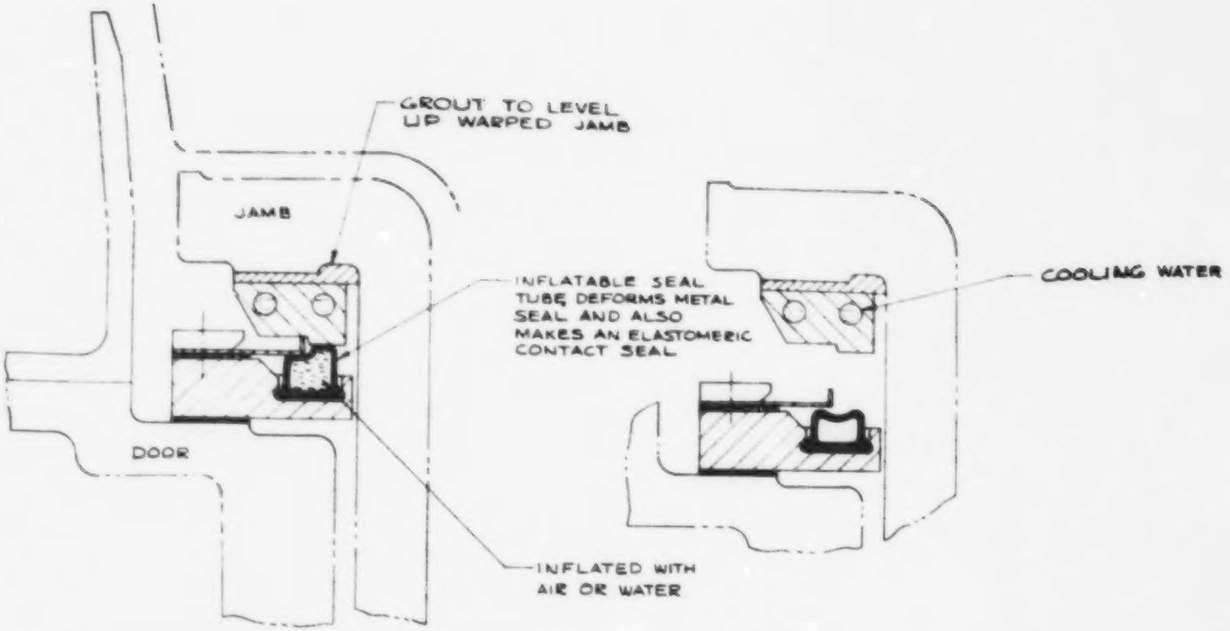
KOPPERS
4-5


SHIM AND GROUT TO CORRECT JAMB WARPAGE
JAMB
INFLATED WITH AIR OR WATER TO DEFLECT METAL SEAL
DOOR
CLOSE

This design possibility requires a source of inflating media, possibly air or water. If air is used a pressure bottle might be carried on the door machine and the door seal could be inflated by using a hose like when filling an auto tire. If water is used to cool the elastomer, a water supply, water treatment and cooling facility as well as circulating pumps and distribution plumbing are required. The seal could be replaced only with the door horizontal in a maintenance station.

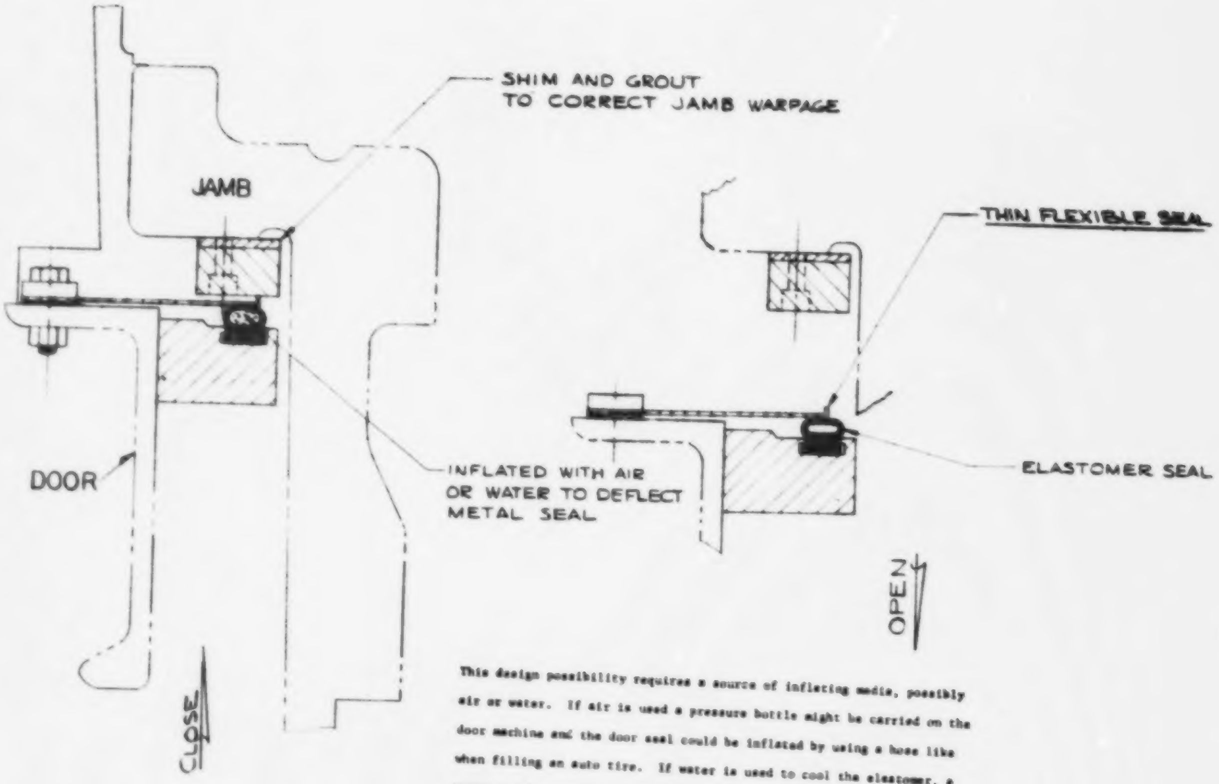


KOPPERS
4-6



This design possibility requires a source of inflating media, possibly air or water. If air is used a pressure bottle might be carried on the door machine and the door seal could be inflated by using a hose like when filling an auto tire. If water is used to cool the elastomer, a water supply, water treatment and cooling facility as well as circulating pumps and distribution plumbing are required. The seal could be replaced only with the door horizontal in a maintenance station.

KOPPERS
4-7



This design possibility requires a source of inflating media, possibly air or water. If air is used a pressure bottle might be carried on the door machine and the door seal could be inflated by using a hose like when filling an auto tire. If water is used to cool the elastomer, a water supply, water treatment and cooling facility as well as circulating pumps and distribution plumbing are required. The seal could be replaced only with the door horizontal in a maintenance station.

WILPUTTE
4-8

Door Jambs. Existing door jambs of various designs are compatible with this concept, except as follows:

(1) Extreme "hourglass" distortion would restrict door placement and removal.

(2) If a seal component is to be added to the jamb (see Drawings 4-1 and 4-3) this component could be shimmed and grouted to re-establish flatness of a warped jamb. Presently acceptable degree of flatness of the jamb is not detrimental if no seal component is to be added to the jamb. The inflatable tube could conform to a warped jamb.

Seal Components. Existing door seals of various designs could be compatible with this concept and could be retained as a secondary sealing mechanism. However, existing seals would be replaced with similar features which would provide secondary sealing as well as protection for the elastomeric tube. The elastomeric tube would required protection from (1) radiant as well as conductive heat, (2) mechanical damage, (3) oven-gas chemicals, and (4) contact with hot coke. Means for accomplishing these requirements are specifically noted, where provided, in the sketches of design possibilities.

Oven Doors. Existing doors of various designs are compatible with this concept and would be retained with slight modifications such as:

(1) Elimination of existing seal components and plugging of any resulting openings.

(2) Addition of new seal components by bolting or welding.

(3) Addition of holes for injection of back-pressurizing gas.

Cleaning. Cleaning required by this concept would be accomplished by scraper mechanisms mounted on the door machine if metal seal areas are to be cleaned. However, if the elastomeric tube should require cleaning, automated, high-pressure jets mounted in the door machine could be used. High-pressure water jets might be utilized for both door and jamb areas, on both metal surfaces and elastomeric tubes. Cleaning of the elastomeric seal is minimized by inboard, secondary-seal features which would exclude gross intrusion of particulates. Between the secondary seal and the elastomeric tube, a back-pressurizing gas might be injected to more completely exclude intrusion of oven vapors to the elastomer, thus preventing coal-volatiles from condensing.

Seal Concept Family 5 - Contact Seals

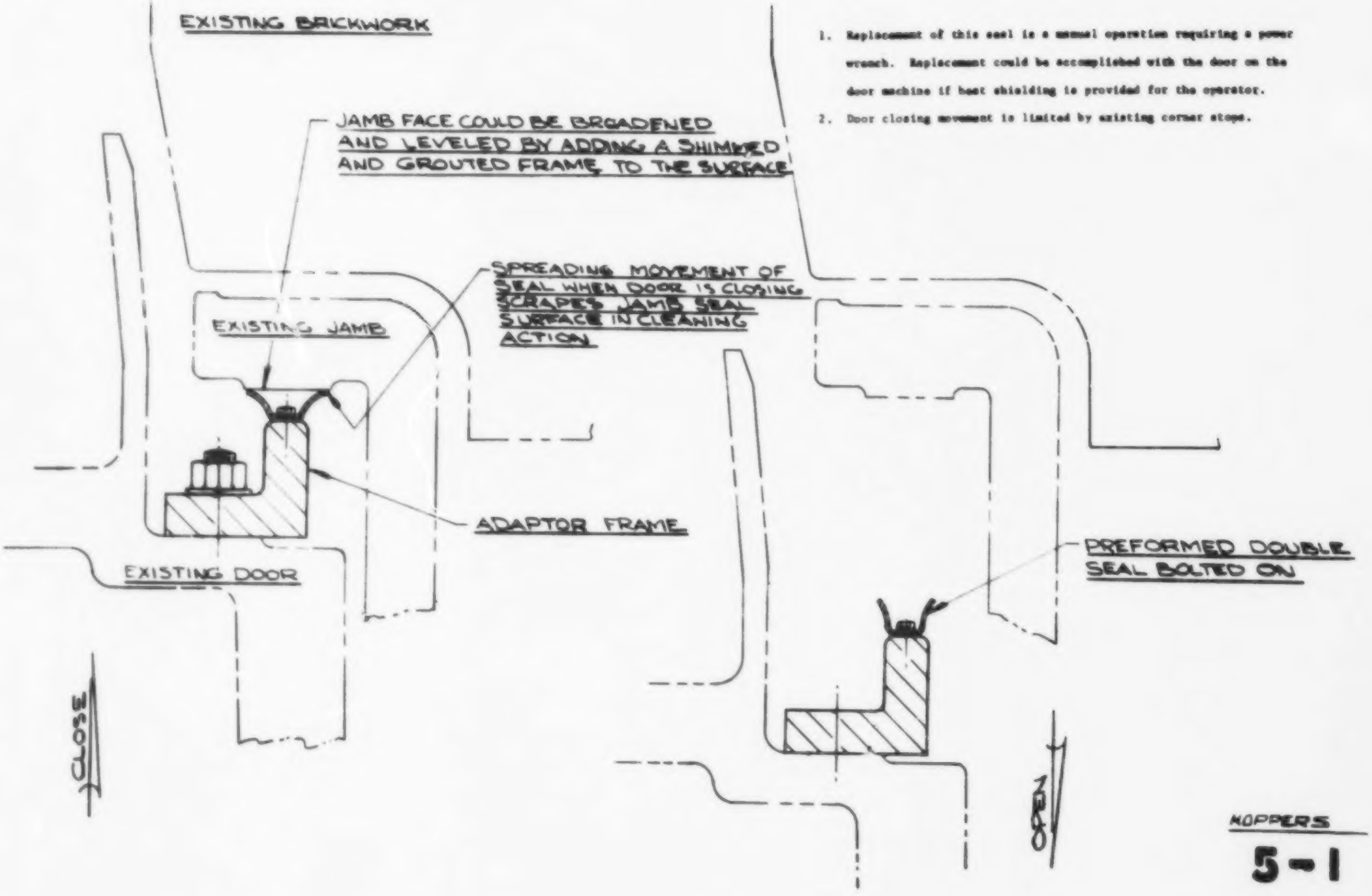
This concept involves seals located in the conventional zone of the existing knife-edge seals. This concept is similar to existing knife-edge seals in that it employs metal-to-metal contact. One of the contacting metal members must be sufficiently flexible to conform to the irregularities of the other metal member, usually the jamb. The same contacting metal member must also possess adequate spring characteristics to transfer latching forces properly to its sealing edge.

Experiments (Chapter IV) have demonstrated that bright, thoroughly clean, metal sealing members with typical surface finishes will not seal coke-oven gas pressures. A period of time is required for volatiles to condense and to form a seal from deposits of tars.

Design possibilities illustrating this concept are illustrated in Drawings 5-1 through 5-14. The following discussion of the concept refers to these illustrations and reveals relationships between the concept and conventional designs of ovens and operating equipment.

Door Jambs. Existing door jambs of various designs are compatible with this concept, except that extreme "hourglass" distortion would restrict door placement and removal. Moderate degree of flatness of the jamb is not detrimental to application of the concept. A method of improving flatness of the sealing surface of existing jambs is shown in some of the figures.

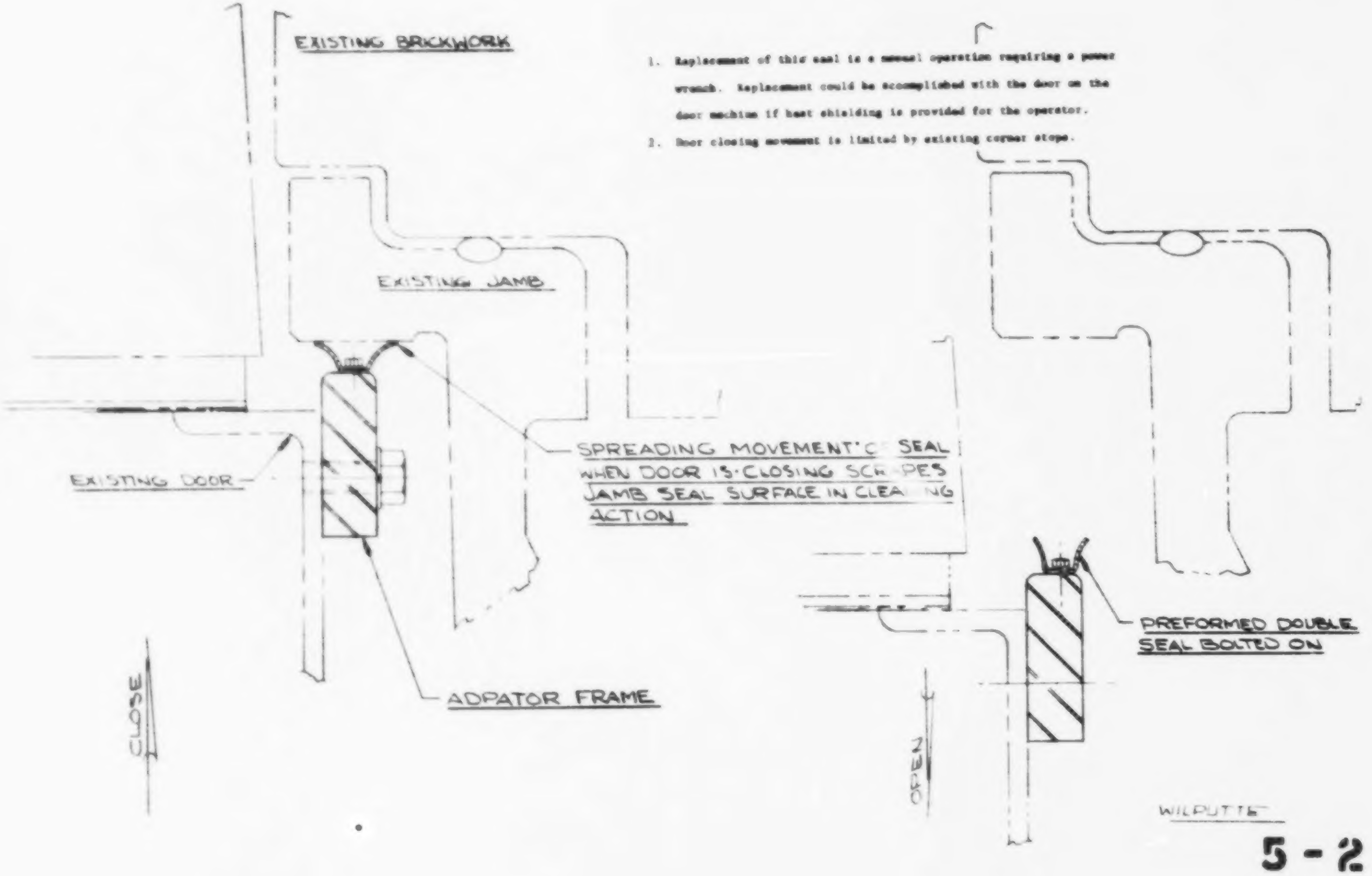
Seal Components. This concept requires the replacement of all existing seal components with components of new design. A possible exception is the sealing surface on the jamb, as discussed under door jambs.


EXISTING BRICKWORK
JAMB FACE COULD BE BROADENED AND LEVELED BY ADDING A SHIMMED AND GROUTED FRAME TO THE SURFACE
SPREADING MOVEMENT OF SEAL WHEN DOOR IS CLOSING SCRAPES JAMB SEAL SURFACE IN CLEANING ACTION
EXISTING JAMB
ADAPTOR FRAME
EXISTING DOOR
CLOSE
PREFORMED DOUBLE SEAL BOLTED ON
OPEN

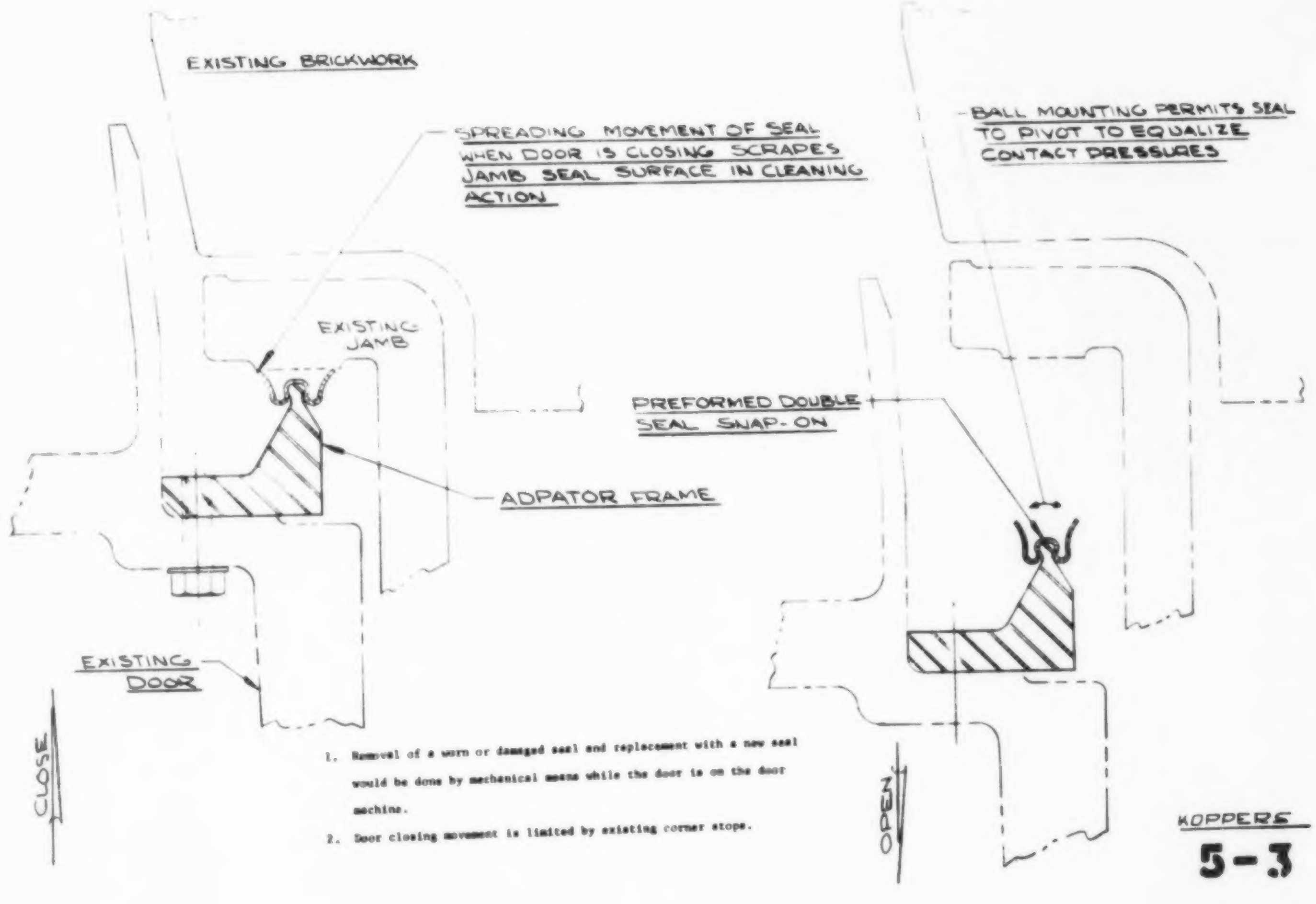
1. Replacement of this seal is a manual operation requiring a power wrench. Replacement could be accomplished with the door on the door machine if heat shielding is provided for the operator.
2. Door closing movement is limited by existing corner stops.

KOPPERS

5-1


EXISTING BRICKWORK
EXISTING JAMB
EXISTING DOOR
SPREADING MOVEMENT OF SEAL WHEN DOOR IS CLOSING SCRAPES JAMB SEAL SURFACE IN CLEANING ACTION
ADPATOR FRAME
CLOSE
OPEN
PREFORMED DOUBLE SEAL BOLTED ON
WILPUTTE
5 - 2

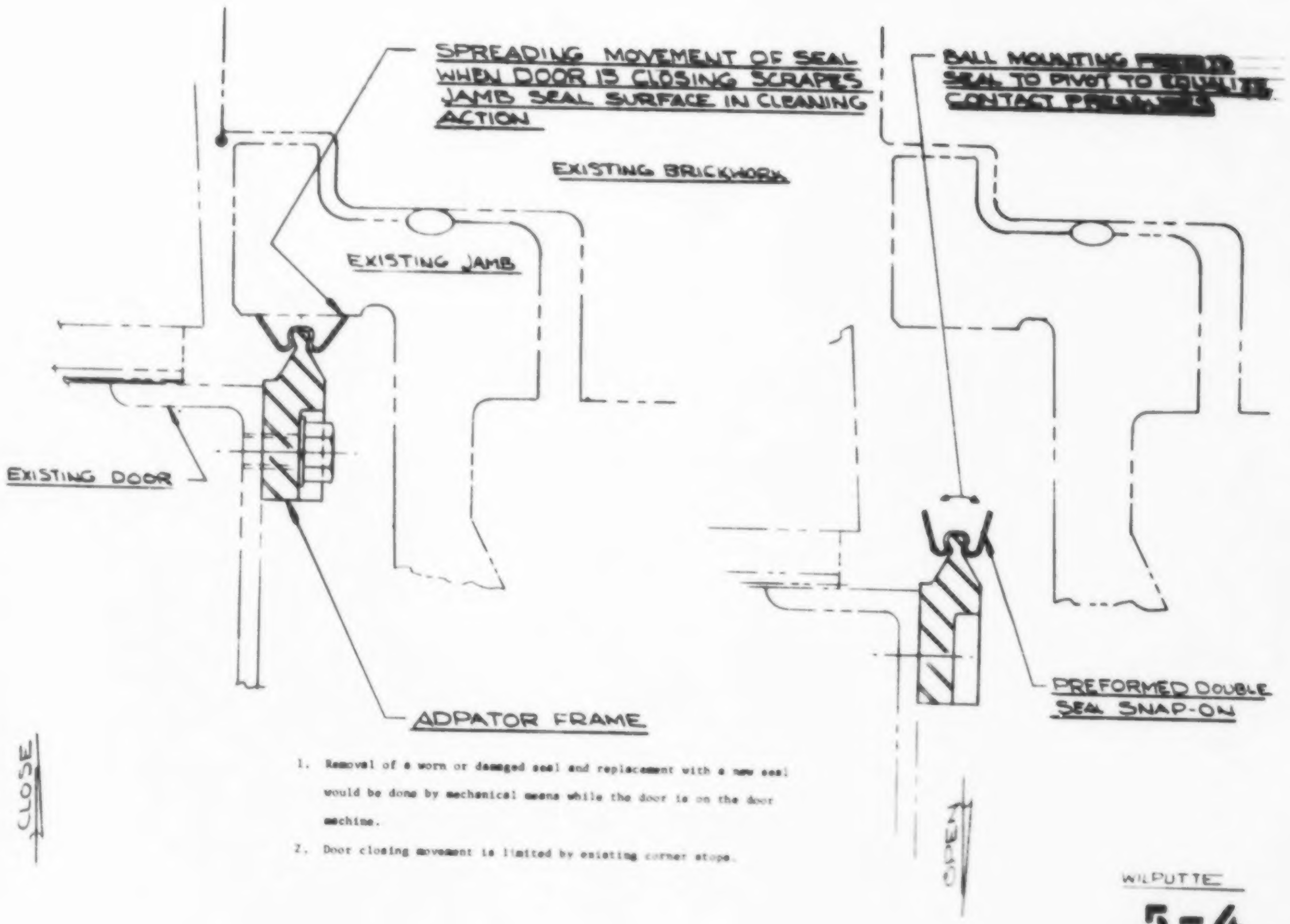
1. Replacement of this seal is a manual operation requiring a power wrench. Replacement could be accomplished with the door on the door machine if heat shielding is provided for the operator.
2. Door closing movement is limited by existing corner stops.


EXISTING BRICKWORK
SPREADING MOVEMENT OF SEAL WHEN DOOR IS CLOSING SCRAPES JAMB SEAL SURFACE IN CLEANING ACTION
BALL MOUNTING PERMITS SEAL TO PIVOT TO EQUALIZE CONTACT PRESSURES
EXISTING JAMB
PREFORMED DOUBLE SEAL SNAP-ON
ADPATOR FRAME
EXISTING DOOR
CLOSE
OPEN

1. Removal of a worn or damaged seal and replacement with a new seal would be done by mechanical means while the door is on the door machine.
2. Door closing movement is limited by existing corner stops.

KOPPERS

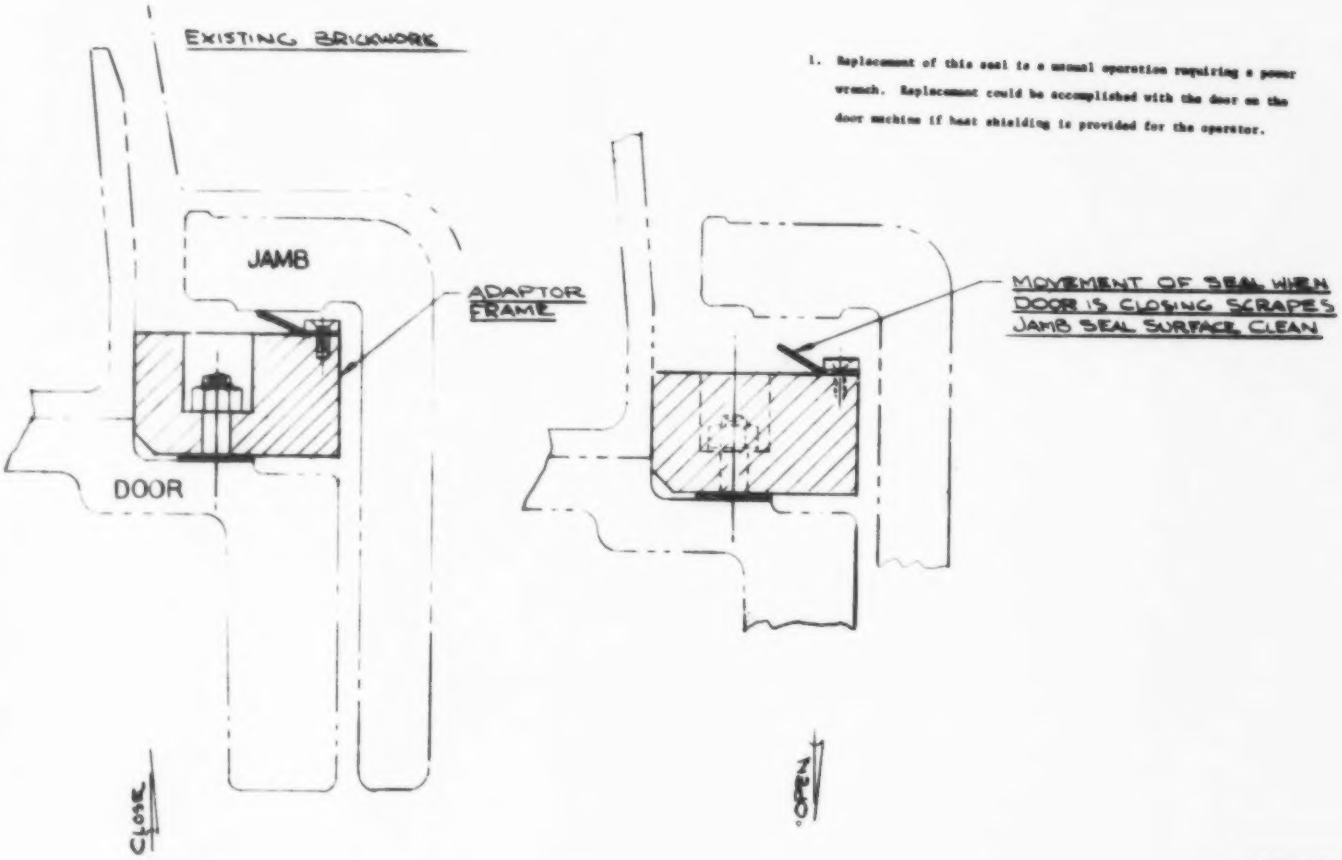
5-3


SPREADING MOVEMENT OF SEAL WHEN DOOR IS CLOSING SCRAPES JAMB SEAL SURFACE IN CLEANING ACTION
BALL MOUNTING PERMITS SEAL TO PIVOT TO EQUALIZE CONTACT PRESSURES
EXISTING BRICKWORK
EXISTING JAMB
EXISTING DOOR
ADPATOR FRAME
PREFORMED DOUBLE SEAL SNAP-ON
CLOSE
OPEN

1. Removal of a worn or damaged seal and replacement with a new seal would be done by mechanical means while the door is on the door machine.
2. Door closing movement is limited by existing corner stops.

WILPUTTE

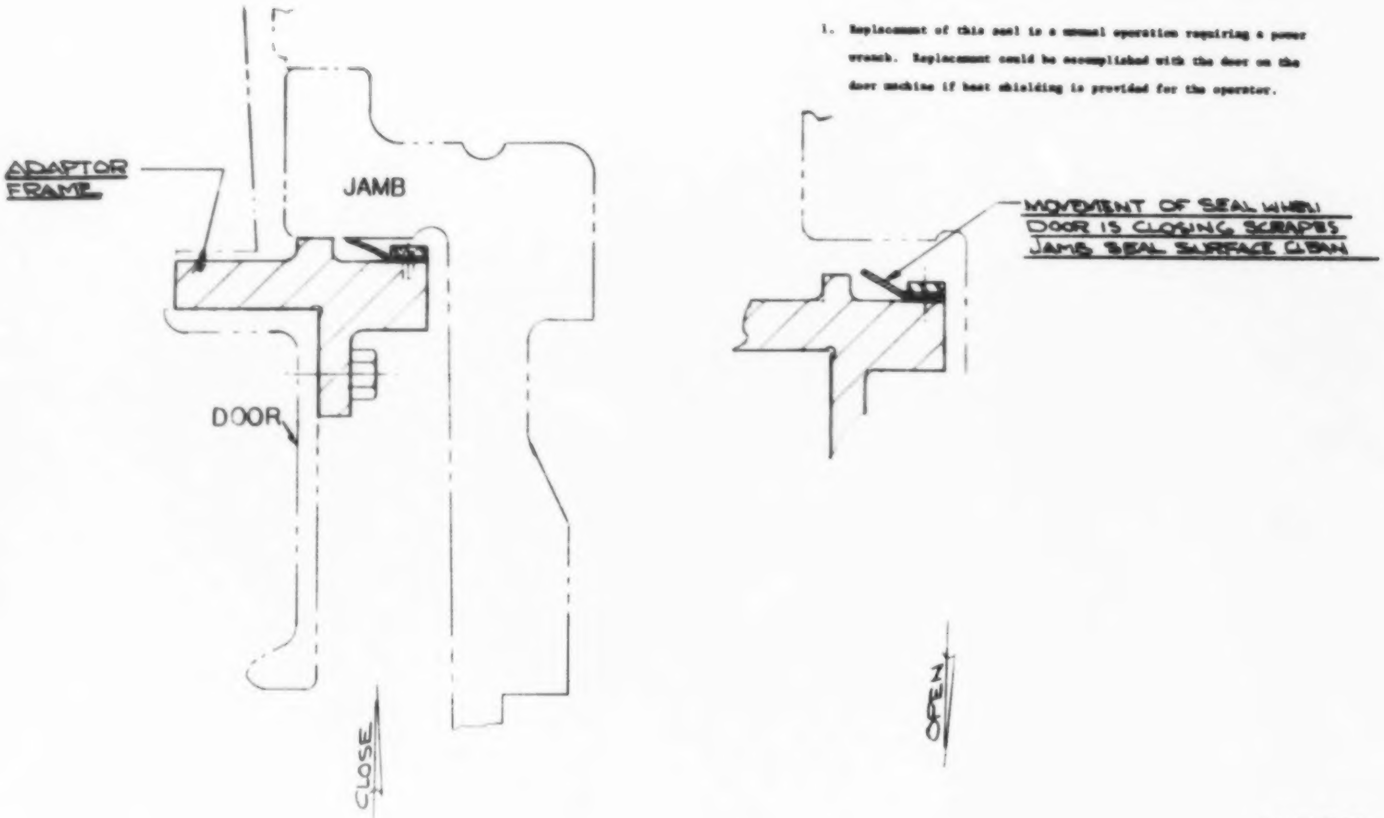
5-4


EXISTING BRICKWORK
JAMB
ADAPTOR FRAME
DOOR
CLOSE
OPEN
MOVEMENT OF SEAL WHEN DOOR IS CLOSING SCRAPES JAMB SEAL SURFACE CLEAN

1. Replacement of this seal is a manual operation requiring a power wrench. Replacement could be accomplished with the door on the door machine if heat shielding is provided for the operator.

KOPPERS

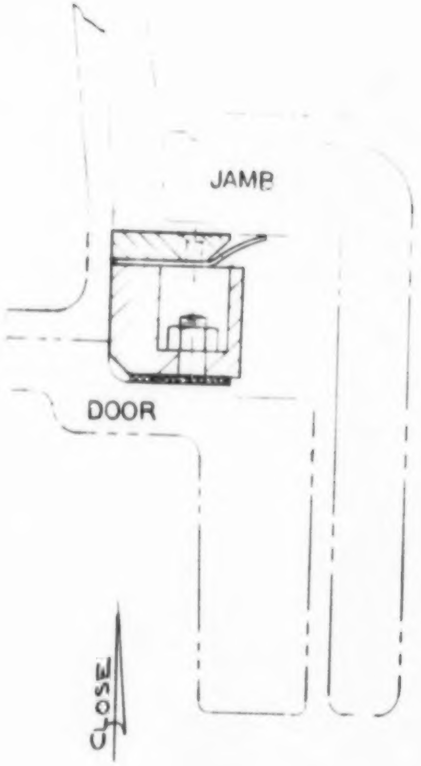
5-5

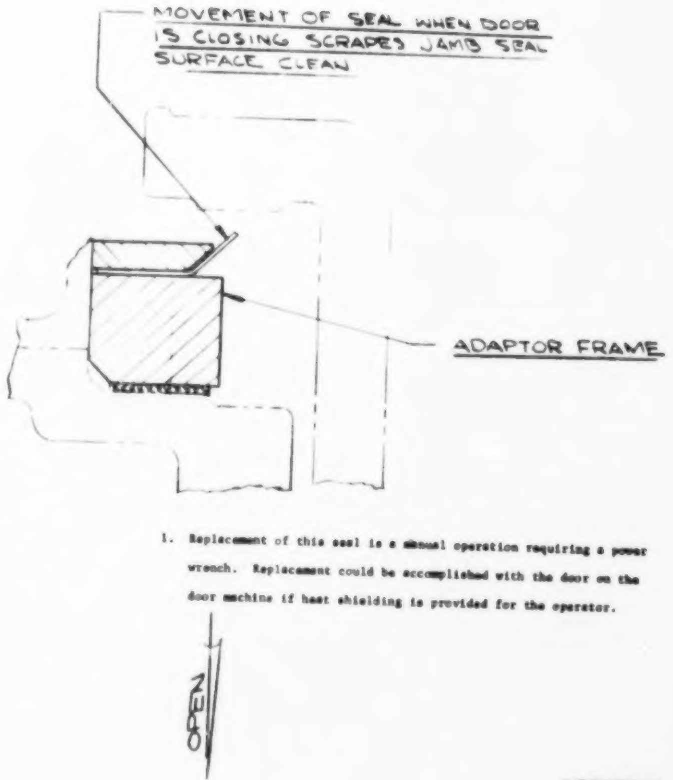

ADAPTOR FRAME
JAMB
DOOR
CLOSE
MOVEMENT OF SEAL WHEN DOOR IS CLOSING SCRAPES JAMB SEAL SURFACE CLEAN
OPEN

1. Replacement of this seal is a manual operation requiring a power wrench. Replacement could be accomplished with the door on the door machine if heat shielding is provided for the operator.

WILPUTTE

5-6

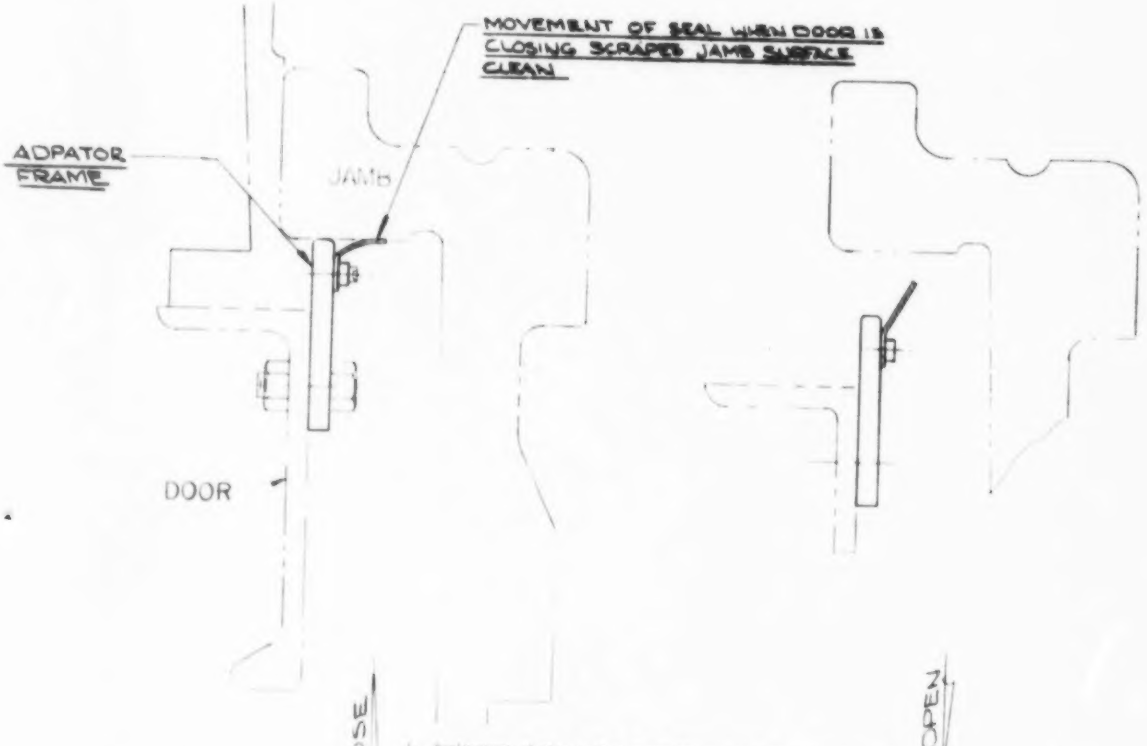



MOVEMENT OF SEAL WHEN DOOR IS CLOSING SCRAPES JAMB SEAL SURFACE CLEAN
ADAPTOR FRAME
OPEN

1. Replacement of this seal is a manual operation requiring a power wrench. Replacement could be accomplished with the door on the door machine if heat shielding is provided for the operator.

KOPPERS

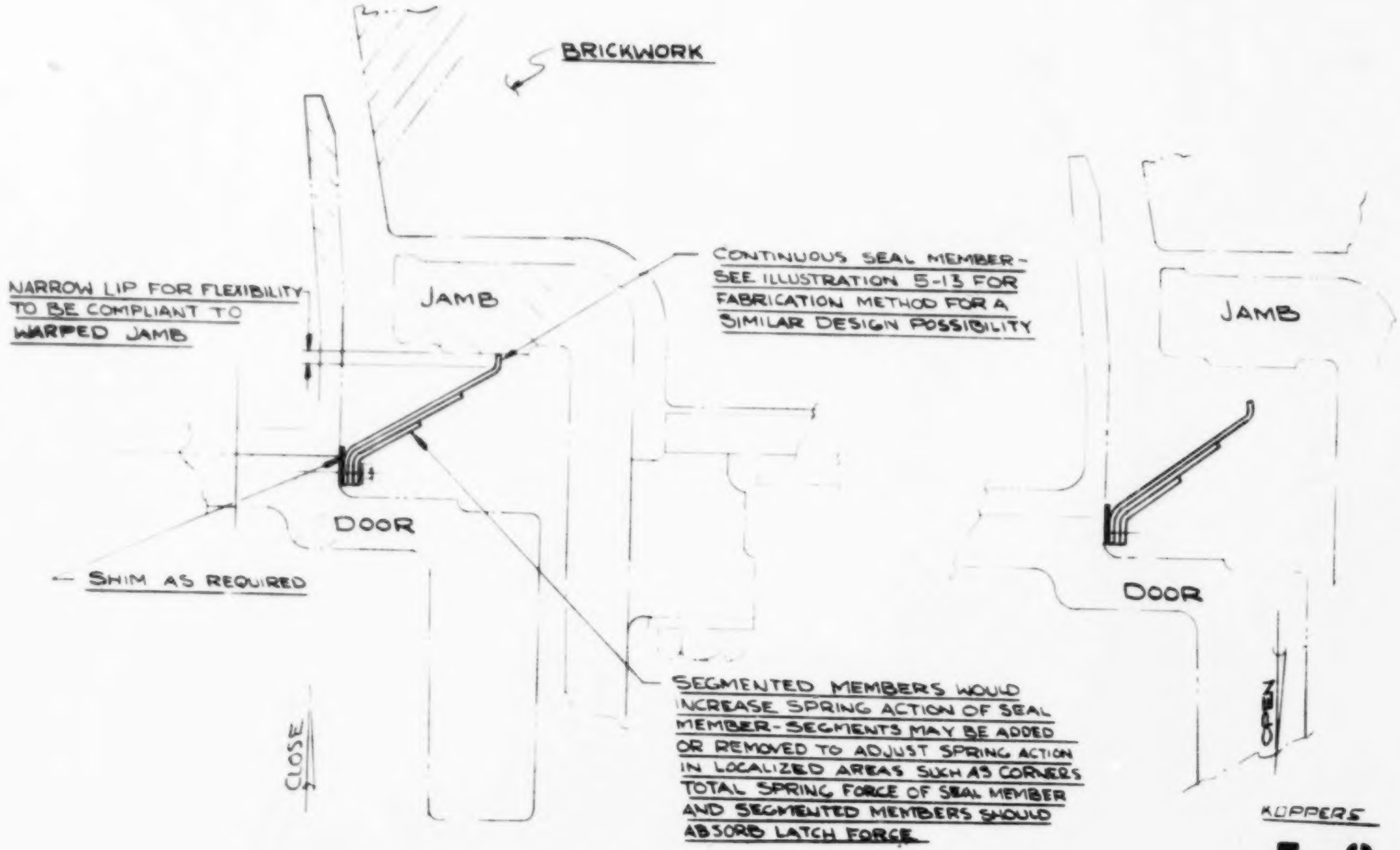
5-7


MOVEMENT OF SEAL WHEN DOOR IS CLOSING SCRAPES JAMB SURFACE CLEAN
ADPATOR FRAME
JAMB
DOOR
CLOSE
OPEN

1. Replacement of this seal is a manual operation requiring a power wrench. Replacement could be accomplished with the door on the door machine if heat shielding is provided for the operator.

WILPUTTE

5-8



NARROW LIP FOR FLEXIBILITY TO BE COMPLIANT TO WARPED JAMB

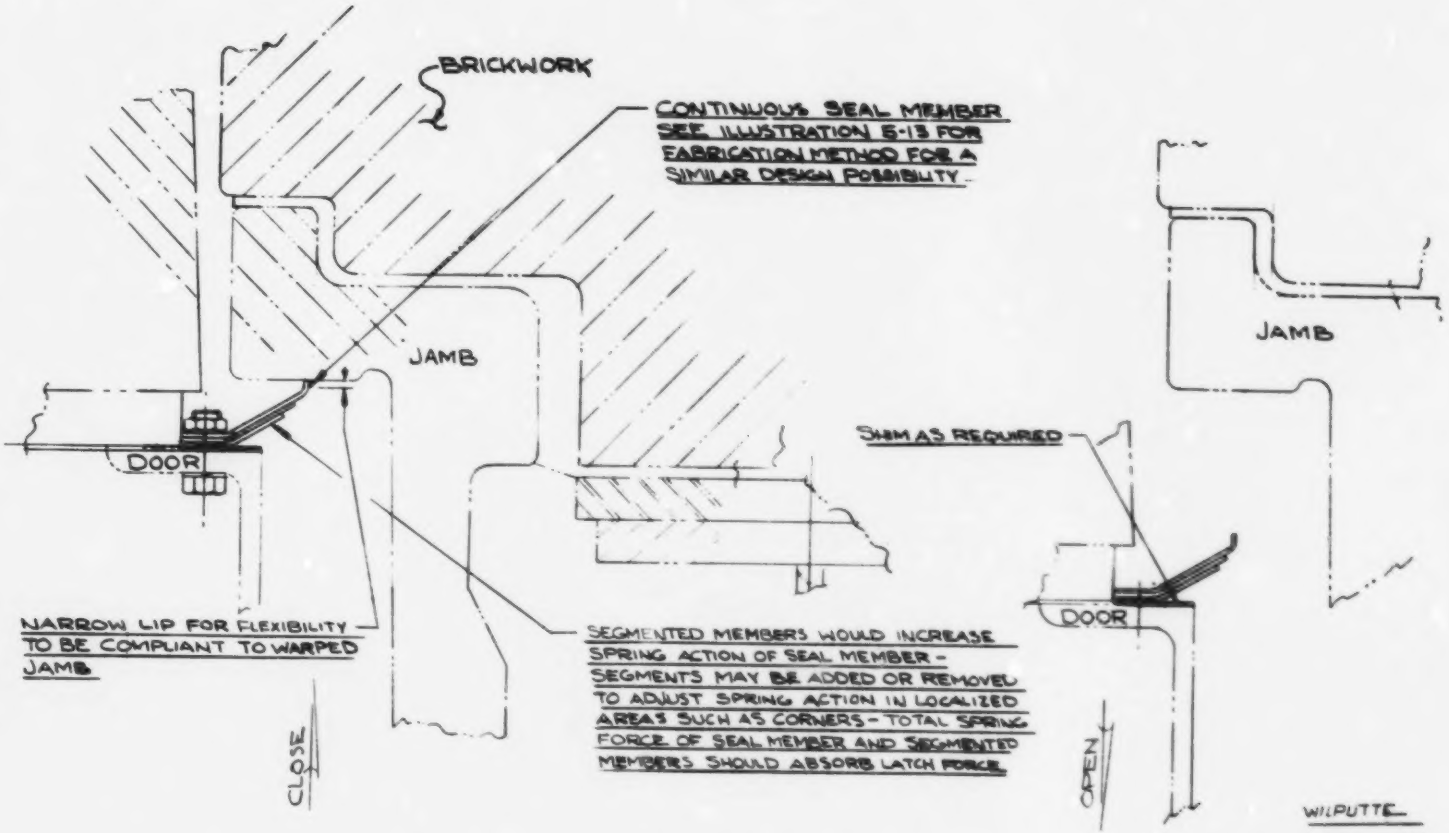
CONTINUOUS SEAL MEMBER - SEE ILLUSTRATION 5-13 FOR FABRICATION METHOD FOR A SIMILAR DESIGN POSSIBILITY

SHIM AS REQUIRED

SEGMENTED MEMBERS WOULD INCREASE SPRING ACTION OF SEAL MEMBER - SEGMENTS MAY BE ADDED OR REMOVED TO ADJUST SPRING ACTION IN LOCALIZED AREAS SUCH AS CORNERS TOTAL SPRING FORCE OF SEAL MEMBER AND SEGMENTED MEMBERS SHOULD ABSORB LATCH FORCE

KOPPERS

5-9



CONTINUOUS SEAL MEMBER SEE ILLUSTRATION 5-13 FOR FABRICATION METHOD FOR A SIMILAR DESIGN POSSIBILITY.

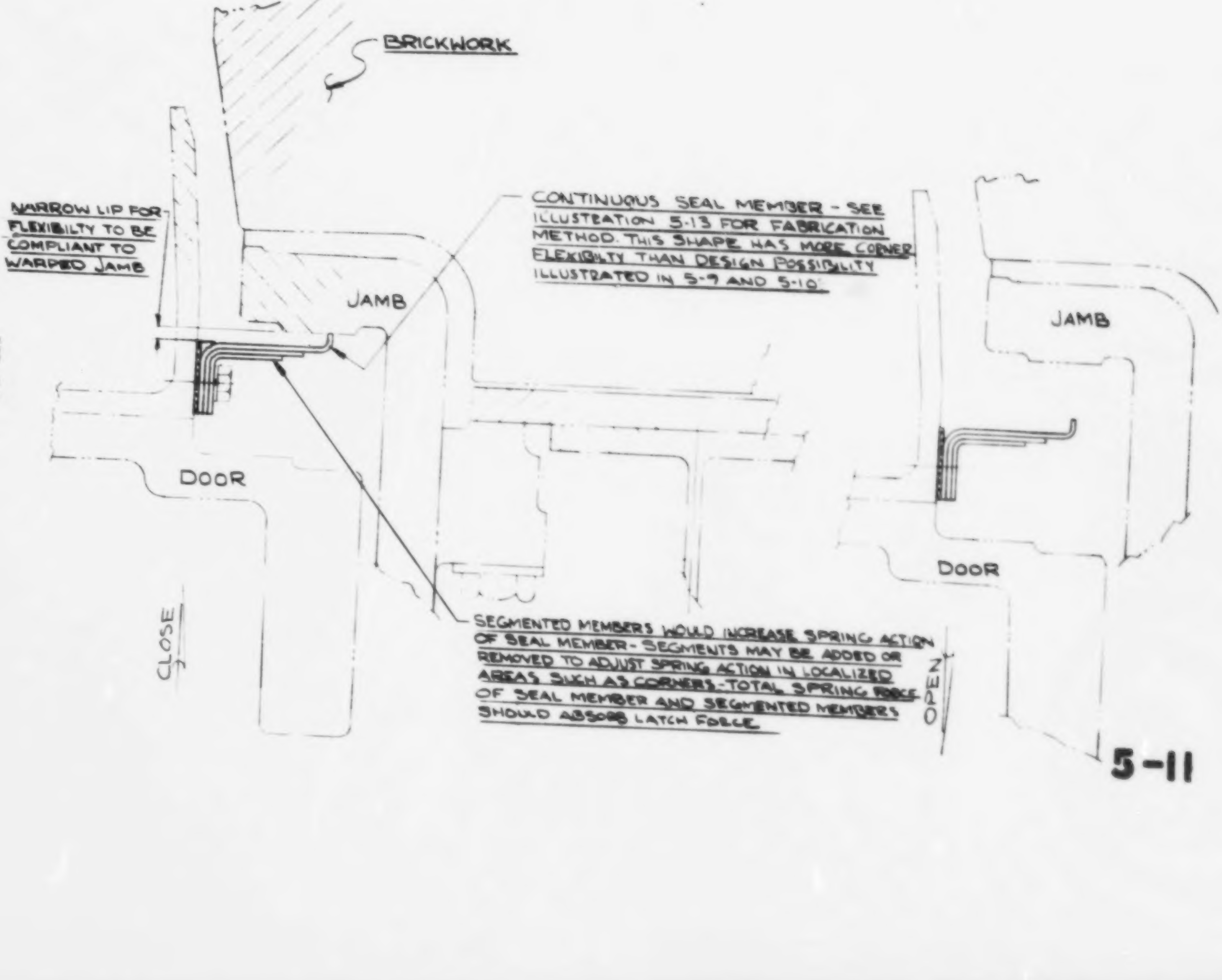
NARROW LIP FOR FLEXIBILITY TO BE COMPLIANT TO WARPED JAMB

SEGMENTED MEMBERS WOULD INCREASE SPRING ACTION OF SEAL MEMBER - SEGMENTS MAY BE ADDED OR REMOVED TO ADJUST SPRING ACTION IN LOCALIZED AREAS SUCH AS CORNERS - TOTAL SPRING FORCE OF SEAL MEMBER AND SEGMENTED MEMBERS SHOULD ABSORB LATCH FORCE.

SIDE SECTION

WILPUTTE

5-10

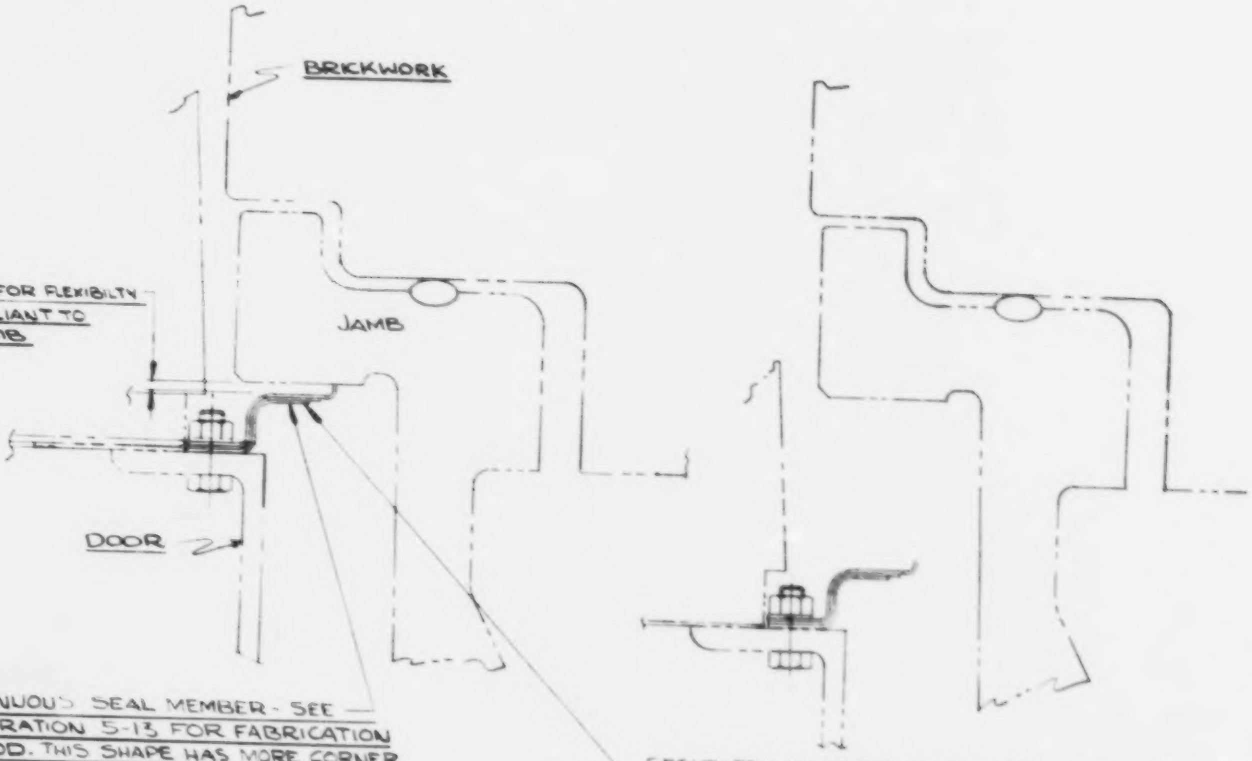


NARROW LIP FOR FLEXIBILTY TO BE COMPLIANT TO WARPED JAMB

CONTINUOUS SEAL MEMBER - SEE ILLUSTRATION 5-13 FOR FABRICATION METHOD. THIS SHAPE HAS MORE CORNER FLEXIBILTY THAN DESIGN POSSIBILITY ILLUSTRATED IN 5-9 AND 5-10.

SEGMENTED MEMBERS WOULD INCREASE SPRING ACTION OF SEAL MEMBER - SEGMENTS MAY BE ADDED OR REMOVED TO ADJUST SPRING ACTION IN LOCALIZED AREAS SUCH AS CORNERS - TOTAL SPRING FORCE OF SEAL MEMBER AND SEGMENTED MEMBERS SHOULD ABSORB LATCH FORCE

5-11

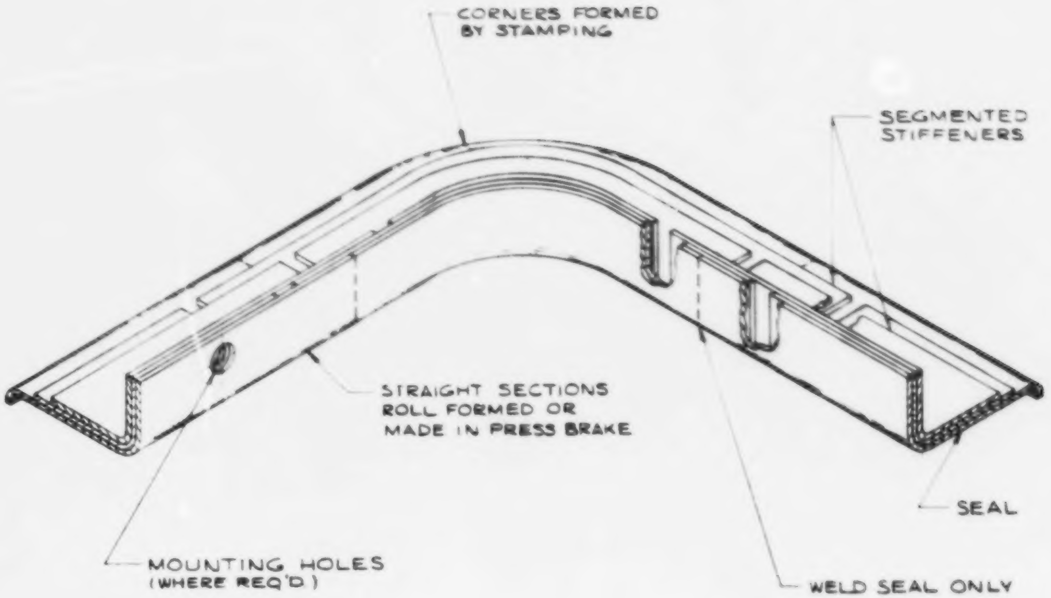


NARROW LIP FOR FLEXIBILTY TO BE COMPLIANT TO WARPED JAMB

CONTINUOUS SEAL MEMBER - SEE ILLUSTRATION 5-13 FOR FABRICATION METHOD. THIS SHAPE HAS MORE CORNER FLEXIBILITY THAN DESIGN POSSIBILITY ILLUSTRATED IN 5-9 AND 5-10

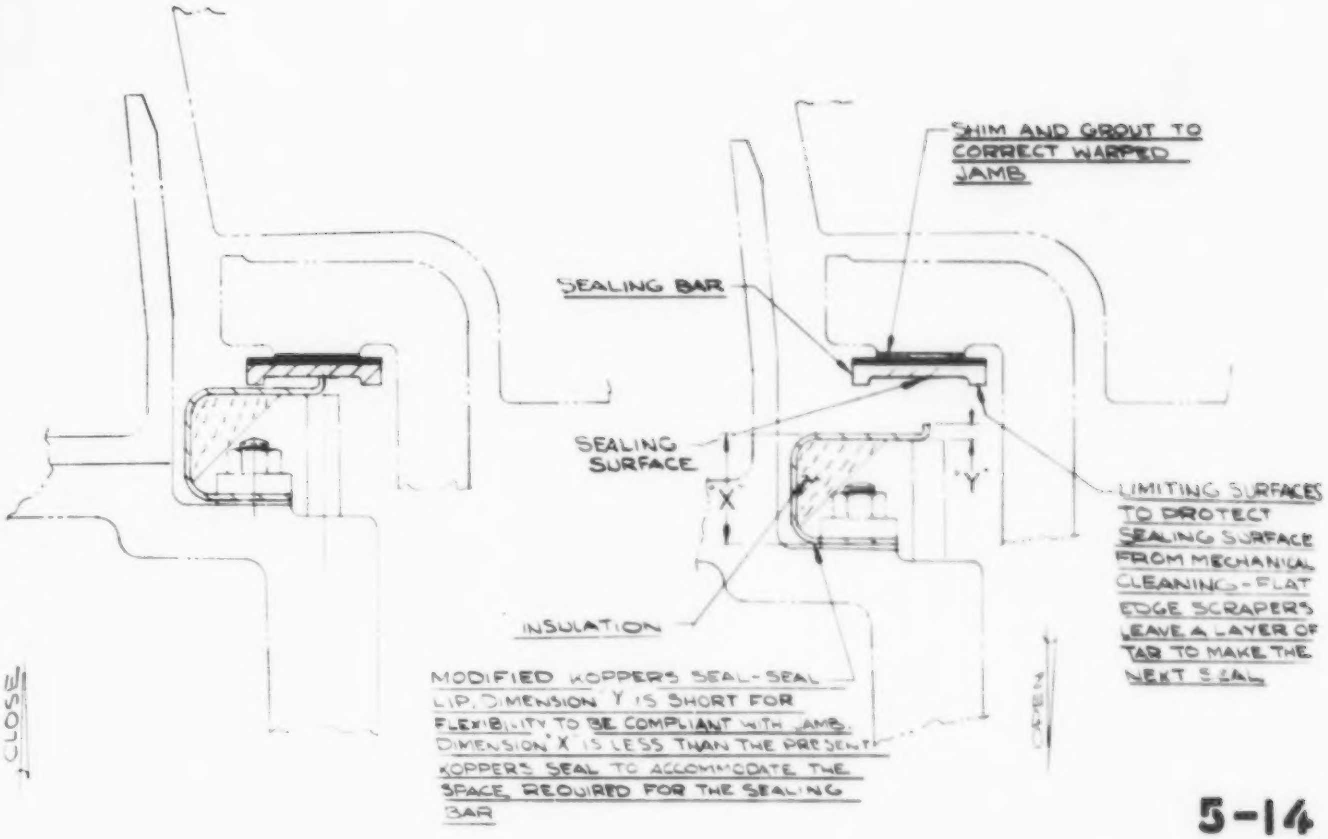
SEGMENTED MEMBERS WOULD INCREASE SPRING ACTION OF SEAL MEMBER - SEGMENTS MAY BE ADDED OR REMOVED TO ADJUST SPRING ACTION IN LOCALIZED AREAS SUCH AS CORNERS - TOTAL SPRING FORCE OF SEAL MEMBER AND SEGMENTED MEMBERS SHOULD ABSORB LATCH FORCE

W.L.PUTTE **5-12**


CORNERS FORMED BY STAMPING
SEGMENTED STIFFENERS
STRAIGHT SECTIONS ROLL FORMED OR MADE IN PRESS BRAKE
SEAL
MOUNTING HOLES (WHERE REQ'D)
WELD SEAL ONLY

ISOMETRIC VIEW SEAL ASSEMBLY
FOR DESIGN CONCEPTS 5-9, 5-10, 5-11, 5-12

5-13

SHIM AND GROUT TO CORRECT WARPED JAMB
SEALING BAR
SEALING SURFACE
LIMITING SURFACES TO PROTECT SEALING SURFACE FROM MECHANICAL CLEANING - FLAT EDGE SCRAPERS LEAVE A LAYER OF TAR TO MAKE THE NEXT SEAL
X
Y
INSULATION
MODIFIED KOPPERS SEAL - SEAL LIP. DIMENSION Y IS SHORT FOR FLEXIBILITY TO BE COMPLIANT WITH JAMB. DIMENSION X IS LESS THAN THE PRESENT KOPPERS SEAL TO ACCOMMODATE THE SPACE REQUIRED FOR THE SEALING BAR
CLOSE
OPEN

5-14

Oven Doors. Existing doors of various designs are compatible with this concept and would be retained with slight modifications such as:

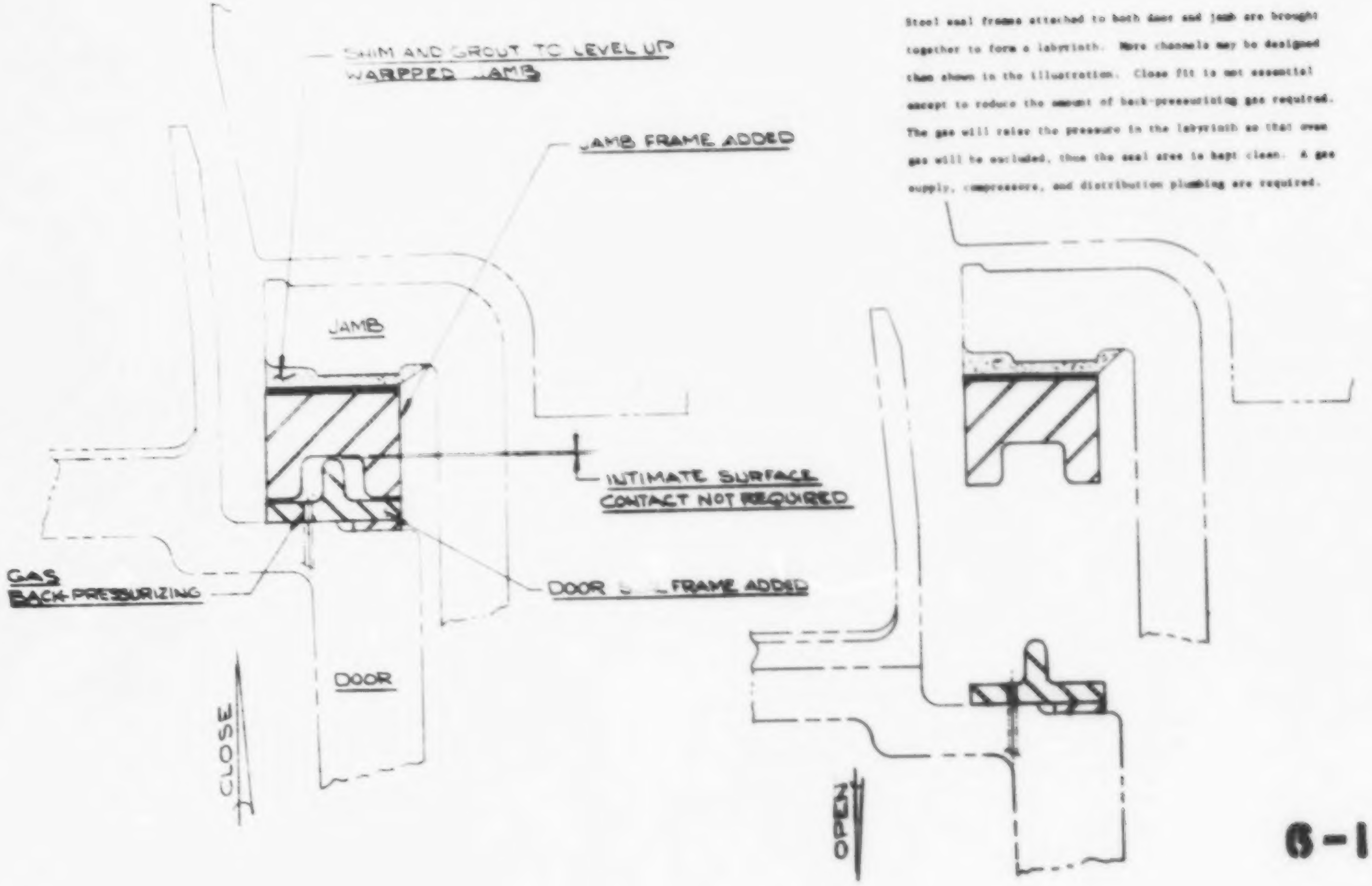
(1) Elimination of existing seal components and plugging of any resulting openings.

(2) Addition of new seal components by bolting or welding.

Cleaning. The purpose of cleaning required for this concept is to achieve a smooth surface but not a bright surface. Cleaning would be accomplished by scraper mechanisms or high-pressure water-jet devices. Scraping might be used for cleaning the jamb and high-pressure water jets for cleaning the seal member. The cleaning mechanisms and devices would be mounted on the door machine.

Seal Concept Family 6 - Noncontact Seal

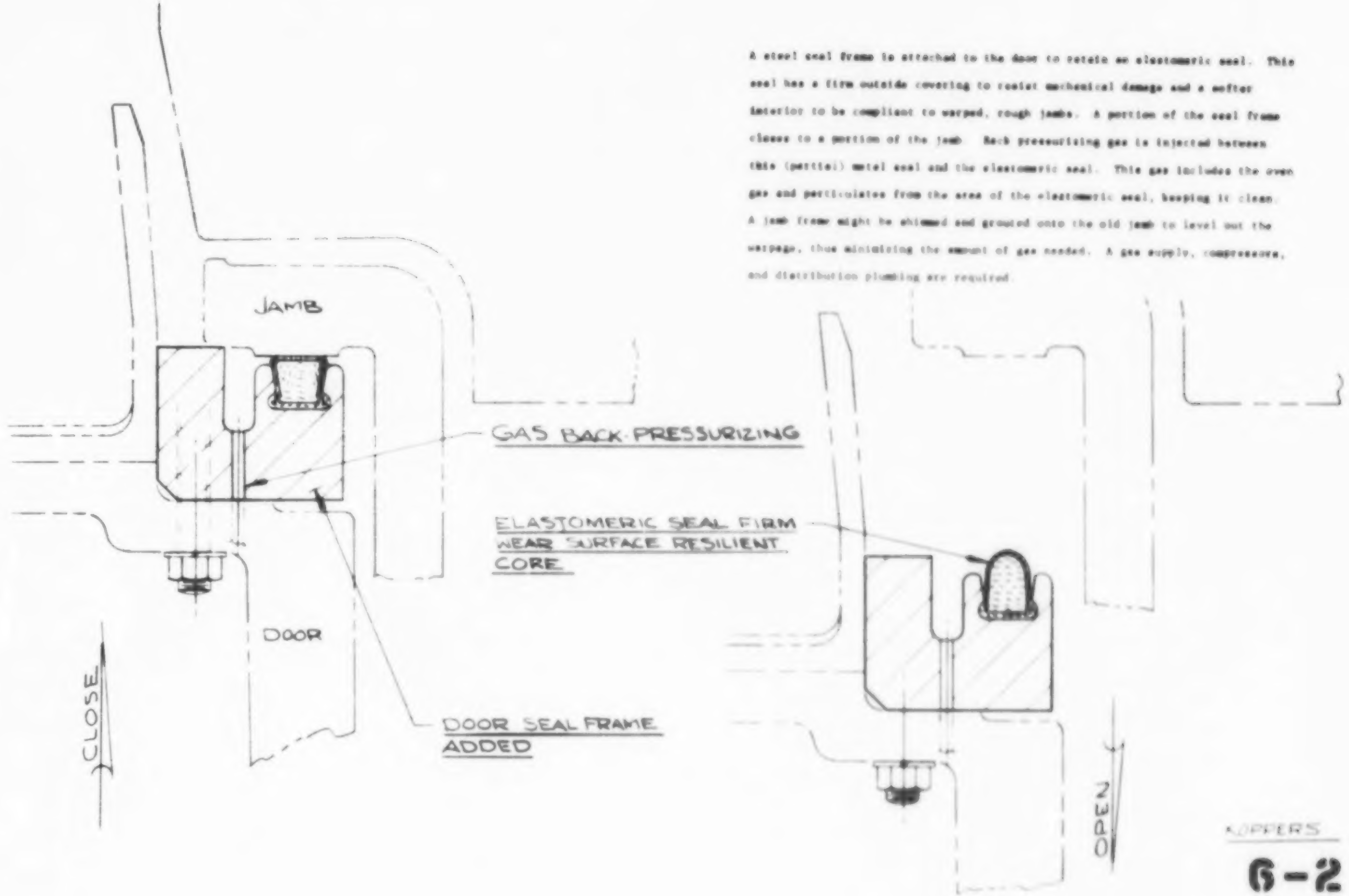
This concept includes seals located in the cold zone or in the conventional sealing area. The intent of this concept is to use pressurized gases in the seal area to retain oven vapors in the oven and to exclude coke-process condensates and particulates from the sealing surfaces. Labyrinth seals, in which intimate contact of mating members is not essential, would retain oven gas pressures by means of injected-gas pressure within the labyrinth. This injected gas must create within the labyrinth pressure which exceeds the internal gas pressure in the oven. Thus the sealing gas will leak into the oven, as well as out to the atmosphere. Therefore, the sealing gas should be atmosphere compatible and also should not affect adversely the quality of coke-oven gas or the coking process. Nitrogen might satisfy these requirements. To minimize the amount of gas consumed in this concept, improvements to jamb flatness are desirable. Additionally, elastomeric seal strips placed outboard from a metal labyrinth can eliminate sealing-gas leakage to the atmosphere. In this arrangement the sealing gas leaks only into the oven, excluding oven gas and volatile condensates from the elastomeric seal and seal area. Several design possibilities illustrating this concept are shown in Drawings 6-1, 6-2, and 6-3. The following discussion of the concept refers to these drawings and reveals relationships between the concept and conventional designs of ovens and operation equipment.



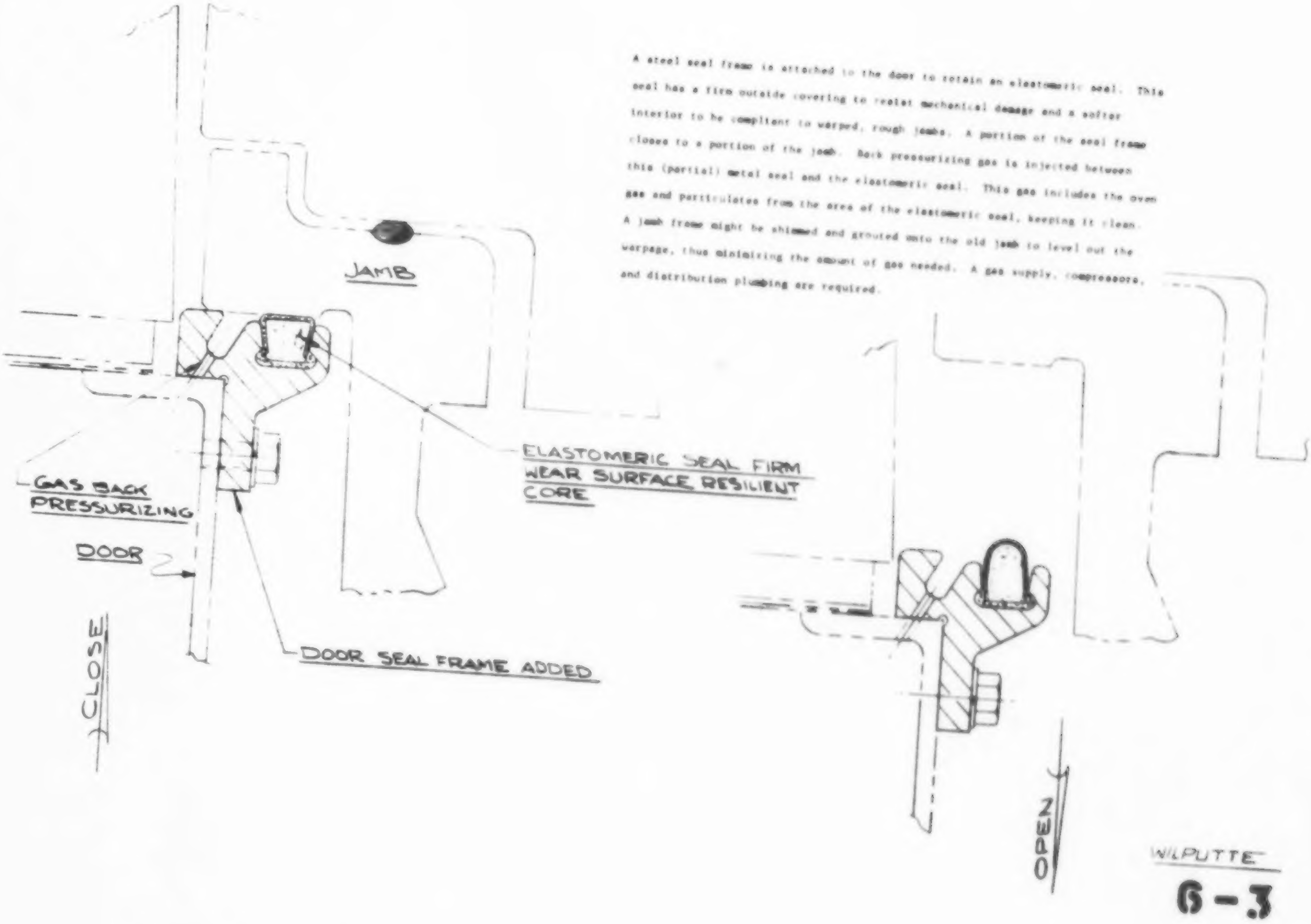
Steel seal frames attached to both door and jamb are brought together to form a labyrinth. More channels may be designed than shown in the illustration. Close fit is not essential except to reduce the amount of back-pressurizing gas required. The gas will raise the pressure in the labyrinth so that oven gas will be excluded, thus the seal area is kept clean. A gas supply, compressors, and distribution plumbing are required.

G-1

A steel seal frame is attached to the door to retain an elastomeric seal. This seal has a firm outside covering to resist mechanical damage and a softer interior to be compliant to warped, rough jambs. A portion of the seal frame closes to a portion of the jamb. Back pressurizing gas is injected between this (partial) metal seal and the elastomeric seal. This gas includes the oven gas and particulates from the area of the elastomeric seal, keeping it clean. A jamb frame might be shimmed and grouted onto the old jamb to level out the warpage, thus minimizing the amount of gas needed. A gas supply, compressors, and distribution plumbing are required.



A steel seal frame is attached to the door to retain an elastomeric seal. This seal has a firm outside covering to resist mechanical damage and a softer interior to be compliant to warped, rough jambs. A portion of the seal frame closes to a portion of the jamb. Back pressurizing gas is injected between this (partial) metal seal and the elastomeric seal. This gas includes the oven gas and particulates from the area of the elastomeric seal, keeping it clean. A jamb frame might be shimmed and grouted onto the old jamb to level out the warpage, thus minimizing the amount of gas needed. A gas supply, compressors, and distribution plumbing are required.



Door Jambs. Existing door jambs of various designs are compatible with this concept, except as follows:

(1) Extreme "hourglass" distortion would restrict door placement and removal.

(2) Presently acceptable degree of flatness of the jamb is not detrimental if no seal component is to be added to the jamb. The elastomeric seal strip could conform to a warped jamb. However, if a seal component is to be added to the jamb (see Drawing 6-1), this component could be shimmed and grouted to re-establish flatness of a warped jamb.

Some jambs may become distorted to an extent that they are unfit for use as a sealing component or are incapable of effective sealing against the brick work. Replacement jambs should be improved to yield a longer effective life.

Seal Components. Existing door-seal components of various designs would be replaced with new seal components on the doors or jambs. New components of labyrinth seals would incorporate features for injection of sealing gas and retention and protection of elastomeric seal components. The elastomeric strip would require protection from (1) radiant as well as conductive heat, (2) mechanical damage, (3) oven-gas chemicals, and (4) contact with hot coke.

Oven Doors. Existing doors of various designs are compatible with this concept and would be retained with slight modifications such as:

(1) Elimination of existing seal components and plugging of any resulting openings.

(2) Addition of new seal components by bolting or welding.

(3) Addition of holes for injection of back-pressurizing gas.

Cleaning. Cleaning required by this concept would be accomplished by mechanized scraper devices mounted on the door machine if metal seal areas are to be cleaned. However, if the elastomeric strip should require cleaning, automated, high-pressure water jets mounted in the door machine would be used. High-pressure-water jets might be utilized for both door and jamb areas, on both metal surfaces and elastomeric tubes. Cleaning of the elastomeric seal is minimized by inboard, secondary-seal features which would exclude gross intrusion of particulates. Between the secondary seal and the elastomeric strip, the back-pressurizing gas would exclude intrusion of oven vapors to the elastomer, thus preventing coal volatiles from condensing.

CHAPTER VII

EVALUATION OF FAMILIES OF SEALING CONCEPTS

The families of sealing concepts described in Chapter VI were evaluated by two methods. The first was a judgmental procedure (using a numerical scoring method) performed by knowledgeable representatives of EPA and AISI and by Battelle personnel familiar with the work. The second evaluation took into consideration the various comments made by evaluators in the first evaluation, and then each concept family was analyzed by Battelle researchers with respect to the seven sealing-system specifications described in Chapter IV. The output from this second evaluation determined Battelle's recommendations.

Initial Judgmental Evaluation of Concept Families by AISI/EPA/BCL

In this evaluation, a broad base of evaluations was sought to apply the collective knowledge and experience of those people who are intimately experienced with the operation and management of coke-plant facilities and who are trained and experienced in conducting research and development programs and in related fields of physical science. The following paragraphs discuss the organizational steps leading to the evaluation, the evaluation procedures, and the analysis of the results.

Evaluation Criteria

Evaluation of concept families to select preferred concepts for further development required establishment of logical and relevant evaluation criteria. In this sense, "preferred concepts" are defined as those which hold the greatest promise for

(1) Successful accomplishment of the requirements of an oven-sealing system, and

(2) Ultimate successful development through experimental design and research to a point of industry usefulness.

Establishment of evaluation criteria to define the requirements of an oven-sealing system involved the efforts of a committee of the joint AISI-EPA sponsorship and the Battelle research team. From experience with previous similar research programs, BCL researchers could suggest typical criteria. However, concentrated effort of the full committee was required to develop acceptable phraseology so that the criteria related specifically to coke ovens. Following are the criteria developed for the evaluation of sealing-concept families.

(1) Relative Effectiveness to Lower Emissions (Stop Smoke). Emissions from coke-oven doors are the result of deterioration of sealing conditions. With this in mind, does this concept have essential elements with potential for (a) stopping or drastically lowering coke-oven emissions, and (b) improving one or more conditions which contribute to leak-producing deterioration?

(2) Operating and Maintenance Costs. The cost of replacing sealing components includes the costs of materials, fabricated components, and labor for replacement and related efforts. It also includes the cost of operating the facilities and equipment required to replace the components. Costs will also be affected by whether the sealing components may be replaced while the door is on the door machine at the oven or whether the door must be removed to a service area. How does this concept compare with others?

(3) Capability of Retrofit. Can this concept be adapted to existing battery designs of various types or variations? (a) Can it be retrofitted to present types of ovens with minimum effort; i.e., by the use of clip-on devices or by the use of drilled or tapped holes in existing components, or does it require more extensive modification or redesign of components? (b) Is the concept adaptable to

different types of ovens without requiring significantly different variations of the concept? (c) Does the concept hold promise of working on ovens of any practical size? (d) Will the concept function without changing existing door machinery, will it require minor changes, or will it require extensive changes of and/or additions to the door machinery?

(4) Life. Will the sealing components of this concept, other than expendable sealants if used, have the dependability and repeatability to be effective for 6 months? Six months is a period common to some schedules for repair and replacement of existing seals independent of major repair schedules involving plugs, etc. Six months is chosen for this criterion so that all evaluators will have identical, objective criteria.

(5) Environment and Safety. What is the effect of this concept on operator safety? Can this concept perform without creating new environmental problems when the door is on the oven or at other times in the cycle?

(6) Effect on Cycle/Schedule. There are periods at any coke-oven battery when the charging and pushing operations (including door handling) are completed in the shortest possible time; i.e., there is a departure from time-spaced operations. Does this concept increase the "shortest possible time"? Will this concept permit the pushing/charging function to be accomplished with no increase in the time presently required?

(7) Sensitivity. What is the sensitivity of the concept to damage, error, abuse, or nonstandard operating conditions? Will component failure be the result of deterioration, or is there a possibility of complete failure of a component during a coking cycle?

(8) Relative Cost Installed. What is the cost of acquisition and initial installation of the concept using a 100-oven battery as a base for comparing one concept with others? Costs may include but not be limited to materials, fabrication of components, labor, downtime,

new or modified ancillary equipment, and provisions for utilities. Engineering to retrofit to a specific battery will add to the cost.

(9) Effect on Coke Quality. Will this concept be free of adverse effects on coke quality?

(10) Operation Complexity and Operator Options. Both management and workers appreciate that best results are obtained when a procedure is straightforward and uncomplicated with option-related decisions. Are operator procedural options limited effectively by the concept to avoid procedural errors?

(11) Availability of Expendable Materials or Components. Are expendable materials, if used, readily available and are they likely to remain so? Are expendable components readily and simply fabricated, or do they require complex fabrication methods and facilities which sometimes lead to delays?

(12) Maintainability. Can expendable items be replaced by using familiar and durable tools? Can any of this work be accomplished while the door is on the door machine with proper heat shielding for the maintenance crew? Can existing levels of skill of maintenance personnel be used in the setup and maintenance of this concept or will higher-level skills be required?

(13) Cleanability. Will the cleaning provision described in this concept provide adequate cleaning without penalty of time or reliability?

(14) Operator Skill Requirements. Can this concept be effectively operational with the present levels of operator skill?

(15) Cost for Development. Development costs include engineering, material investigations, pilot models, instrumentation, field tests, field modifications, etc. These are the costs to develop

and prove the concept before it is engineered for retrofit to specific batteries. How do these costs compare with those for other concepts?

Weighting of Evaluation Criteria

Weighting factors for the evaluation criteria were established by mutual agreement between AISI, EPA, and Battelle personnel. The weighting factor indicates the relative importance of the criteria. The weighting factors are shown below (see also Figure VII-1).

		Weighting Factor
(1)	Relative Effectiveness to Lower Emissions (Stop Smoke)	10
(2)	Operating and Maintenance Costs	10
(3)	Capability of Retrofit	9
(4)	Life	8
(5)	Environment and Safety	8
(6)	Effect on Cycle/Schedule	7
(7)	Sensitivity	6
(8)	Relative Cost Installed	6
(9)	Effect on Coke Quality	6
(10)	Operation Complexity and Operator Options	4
(11)	Availability of Expendable Materials or Components	4
(12)	Maintainability	4
(13)	Cleanability	2
(14)	Operator Skill Requirements	2
(15)	Cost for Development	1

Scoring Values

Scoring values used by evaluators were on a scale of 1 to 5 defined below.

CONCEPTS			CRITERIA																		
NO.	DESCRIPTION	WEIGHTING FACTOR →	EFFECTIVENESS TO REDUCE EMISSION	OPERATING COST	RETROFITABILITY	LIFE	ENVIRONMENTAL PROBLEMS	EFFECT ON CYCLE	SENSITIVITY	RELATIVE COST INSTALLED	EFFECT ON COKE QUALITY	OPERATOR OPTIONS	AVAILABILITY OF MATERIALS	MAINTAINABILITY	CLEANABILITY	OPERATOR SKILL	COST FOR DEVELOPMENT	WEIGHTED TOTALS	% OF MAX. SCORE	RANK	COMMENTS
			10	10	9	8	8	7	6	6	6	4	4	4	2	2	1				
1	HOT ZONE SEALS	→																			
2	LUTED SEALS	→																			
3	RESILIENT SEALS	→																			
4	INFLATABLE SEALS	→																			
5	CONTACT SEALS	→																			
6	NON-CONTACT SEALS	→																			
		→																			
		→																			
		→																			
		→																			

FIGURE VII-1. EVALUATION WORKSHEET

Score	Definition
1	Poor: Most certainly believed to be unacceptable by evidence, prior practice, or closely related experience.
2	Fair: Believed to be unacceptable by somewhat related evidence or experience, but not demonstrated by prior practice.
3	Average: Not believed to be unacceptable by evidence or experience but no strong feeling for acceptability.
4	Good: Believed to be acceptable by somewhat related evidence, experience, or prior practice.
5	Excellent: Most certainly believed to be acceptable by evidence, prior practice, or closely related experience.

For each concept grouping, each criterion was judged relative to:

1. The above definitions of the scoring values, and
2. The other sealing concepts.

At a meeting with the evaluators, it was emphasized that concepts were to be judged and not designs. Each evaluator was asked to visualize the extent to which he believed it possible that skillful, experienced designers could create successful hardware systems representing the concept.

A Listing of the Evaluators

The establishment of evaluation criteria and the weighting factors assigned to these criteria was completed by committee action. However, the evaluation of concepts was done, with one exception, by individual evaluators acting independently. The EPA elected to submit a consensus evaluation acting through the Project Officer. A listing of the evaluators and their affiliations follows:

Evaluator's Name	Organization
A. M. Cameron	Algoma Steel Corp., Ltd., Sault Ste. Marie, Ontario, Canada
L. G. Gainer	U. S. Steel Corp., Clairton, Pennsylvania
T. R. Greer	Jones & Laughlin Steel Corp., Pittsburgh, Pennsylvania
D. S. Gregg	Empire-Detroit Steel Corp., Portsmouth, Ohio
A. O. Hoffman	Battelle's Columbus Laboratories, Columbus, Ohio
L. M. Hoopes	Republic Steel Corp., Youngstown, Ohio
R. E. Maringer	Battelle's Columbus Laboratories, Columbus, Ohio
J. C. McCord	Bethlehem Steel Corp., Lackawanna, New York
J. G. Munson, Jr.	U. S. Steel Corp., Pittsburgh, Pennsylvania
R. L. Paul	Battelle's Columbus Laboratories, Columbus, Ohio
R. G. Phelps	Inland Steel Co., Indiana Harbor, Indiana
E. E. Reiber	Battelle's Columbus Laboratories, Columbus, Ohio
R. D. Rovang, et al	U. S. Environmental Protection Agency, Research Triangle Park, North Carolina
J. Varga, Jr.	Battelle's Columbus Laboratories, Columbus, Ohio

Scoring Procedure

Each evaluator at EPA, AISI, and BCL considered each concept relative to each criterion and marked a score in the appropriate block (indicated by arrows) of the evaluation work sheet. Figure VII-1 is an example of this evaluation work sheet. Although estimates of costs were not given, relative estimates were made by each evaluator with the smallest cost requirements being most acceptable. Generally, the criteria relating to cost were evaluated by considering the cost aspects of all concepts together at the same time. Evaluators were asked for comments relating to concept alternatives. Upon completion of each individual evaluation, the work sheets were analyzed at Battelle.

Ranking of Concepts by Each Evaluator

(1) Each individual score on each work sheet was multiplied by the appropriate weighting factor to produce a base rating.

(2) Base ratings were totalled for each concept.

(3) Total base rating for each concept is reported for each evaluator in Table VII-1.

(4) Ranking of concepts in order of preference was established for each evaluator, as illustrated in Table VII-2.

(5) Concepts are ranked for selected significant criteria for comparison in Table VII-3 to aid interpretation of other statistical results.

Interpretation of Statistical Results

(1) The averages in Table VII-1 do not indicate any strong preference or even a consensus in favor of any single family of concepts.

(2) All groups of evaluators had a low level of overall confidence and feeling for the applicability of Concept Families 1, 3, and 4 (Hot Seals, Resilient Seals, and Inflatable Seals). Their rankings by the various groups were almost completely in the 4th to 6th positions in a list of six.

If only the top three concept families are considered, their rankings by the various groups of evaluators were as shown on page VII-13.

TABLE VII-1. TOTAL BASE RATINGS

Group and Evaluator	CONCEPTS					
	Hot Zone 1	Luted 2	Resilient 3	Inflatable 4	Contact 5	Noncontact 6
AISI						
A	207	246	294	243	379	320
B	234	301	259	286	316	248
C	161	177	121	121	146	185
D	292	293	244	218	264	278
E	300	249	212	210	300	318
F	253	337	332	322	293	312
G	289	309	223	178	283	314
H	318	333	254	223	226	215
AISI Ave.	257	281	242	225	276	274
AISI RANK	4th	1st	5th	6th	2nd	3rd
EPA						
I	218	304	227	219	240	215
EPA RANK	5th	1st	3rd	4th	2nd	6th
BCL						
J	248	253	326	311	366	303
K	416	389	339	338	371	355
L	369	366	311	269	342	286
M	298	321	329	323	361	252
N	163	247	290	266	341	339
BCL Ave.	299	315	319	301	356	327
BCL RANK	6th	4th	3rd	5th	1st	2nd
Overall Ave.	269	295	268	252	302	289
OVERALL RANK	4th	2nd	5th	6th	1st	3rd

TABLE VII-2. RATING OF CONCEPTS

Group and Evaluator	CONCEPTS					
	Hot Zone	Luted	Resilient	Inflatable	Contact	Noncontact
	1	2	3	4	5	6
AISI						
A	6	4	3	5	1	2
B	6	2	4	3	1	5
C	3	2	6	5	4	1
D	2	1	5	6	4	3
E	2	3	4	5	2	1
F	6	1	2	3	5	4
G	3	2	5	6	4	1
H	2	1	3	5	4	6
Frequency	2 3X	1 3X	2 1X	3 2X	1 2X	1 3X
	3 2X	2 3X	3 2X	5 4X	2 1X	2 1X
		3 1X	4 2X	6 2X	4 4X	3 1X
						4 1X
	3 3X	4 1X	5 2X		5 1X	5 1X
			6 1X			6 1X
AISI Rank	4	1	5	6	2	3
EPA RANK	5	1	3	4	2	6
BCL						
J	6	5	2	3	1	4
K	1	2	5	6	3	4
L	1	2	4	6	3	5
M	6	5	3	4	1	2
N	6	5	3	4	1	2
Frequency	1 2X	2 2X	2 1X	3 1X	1 3X	2 2X
	6 3X	5 3X	3 2X	4 2X	3 2X	
			4 1X			
			5 1X	6 2X		4 2X
						5 1X
BCL Rank	6	4	3	5	1	2
Overall						
Frequency	1 2X	1 4X	2 2X	3 3X	1 5X	1 3X
	2 3X	2 5X	3 5X	4 3X	2 2X	2 3X
	3 2X	3 1X	4 3X	5 4X	3 2X	3 1X
		4 1X	5 3X	6 4X	4 4X	4 3X
	5 1X	5 3X	6 1X		5 1X	5 2X
	6 6X					6 2X
Overall Rank	4	2	5	6	1	3

TABLE VII-3. COMPARISON OF RANKING OF CONCEPTS FOR SELECTED CRITERIA

Criteria	Weighting Factor	CONCEPTS Hot-Zone 1	Luted 2	Resilient 3	Inflatable 4	Contact 5	Noncontact 6
All Criteria	-	4	2	5	6	1	3
Effectiveness to Reduce Emissions	10	4	2	2	1	5	3
Operating Cost	10	5	3	4	6	1	2
Life	8	3	1	4	5	2	2
Sensitivity	6	2	1	4	6	5	3
Availability of Materials	4	3	6	4	5	1	2
Maintainability	4	3	1	5	6	2	4
Operator Skill	2	2	1	4	6	3	5

Evaluation Group	Ranking by Concept-Family Name and Average		
	1st	2nd	3rd
AISI	Luted (281)	Contact (276)	Noncontact (274)
EPA	Luted (304)	Contact (240)	Resilient (227)
Battelle	Contact (356)	Noncontact (327)	Resilient (319)

Again, there was no concensus and no firm conclusions could be drawn from these independent evaluations. Subsequent "debriefing" of the Battelle evaluators indicated that their higher rating for contact seals was influenced by (a) the experience of seeing a totally tight, existing metal-to-metal sealing system, and (b) their judgment that a metal-to-metal contact seal could be developed to overcome the shortcomings of the existing seals.

(3) Examination of the selected criteria given in Table VII-3 indicates that, on the average and in terms of effectiveness to reduce emissions, the evaluators gave a higher ranking to luted seals than to contact seals. It is indicated (in Table VII-3) that concerns over "Operating Cost" and "Availability of Materials" kept the luted-seal family of concepts from getting a higher scoring value, especially from the AISI evaluators.

Battelle's Evaluation of Concept Families Via Comparison With Seal-System Specifications and Functional Requirements

The foregoing judgmental evaluation of concept families by the AISI/EPA/BCL groups was completed at about the beginning of the last quarter of this research program. This evaluation was followed by research effort to gain further insights into the practical aspects of the various concept families. In this effort, the comments of the AISI and EPA representatives gave the researchers useful inputs. For example it was learned that some of the AISI evaluators regard the addition of water cooling to the end closures of coke-oven doors as being somewhat impractical if additional problems are created by any interruption in the flow of water.

Battelle's Evaluation and Comments

As a means for presenting the results of the final evaluation, an identification key was developed to indicate the consensus on each of the factors used to grade the various concept families. The key is given in Table VII-4.

TABLE VII-4. IDENTIFICATION KEY FOR CONCEPT-FAMILY EVALUATION

Level of Confidence for Successful Final Development and Performance	■ Probable	▨ Possible	□ Unlikely	XXX Not Possible	? Unknown
Range of Probability	100-90%	90-40%	40-10%	<10%	Unknown

The results of Battelle's final evaluation are shown in Table VII-5. The evaluation was in terms of both the technical specifications and the functional requirements. In this table, an asterisk indicates that there is pertinent discussion in the following text.

The evaluation summary shown in Table VII-5 shows that the Battelle evaluators have a high level of overall confidence in the successful final development and performance of only one concept family; i.e., contact seals. Battelle's use of the term "contact seals" can be considered to be the same as significantly upgraded metal-to-metal seals. In this second and more critical evaluation (see following comments), most of the concept families were downgraded in rating relative to the first evaluations completed by the AISI/EPA/BCL. Only contact seals received a 95 to 100 percent probability rating for each of the specifications and requirement criteria. Stated another way, Battelle researchers believe that existing sealing systems, although often called inadequate, are really marginally successful, and can be improved.

The luted-seal concept family appealed to the AISI and the EPA evaluators. Battelle researchers are aware that foamed-in-place sealants have the potential for completely eliminating emissions from coke-oven doors. In addition, there is a possibility that a simple procedure for foam-sealing of doors could be developed. However, this remains only a possibility at this time. Therefore, the luted-seal concept was downrated by the Battelle investigators. Battelle researchers are, however, recommending further research and testing of this concept family.

TABLE VII-5. A SUMMARY OF BATTELLE'S EVALUATION OF THE SEALING-CONCEPT FAMILIES BASED ON SELECTED SPECIFICATIONS AND FUNCTIONAL REQUIREMENTS

Specifications in Question Form	Concept Family Number and Name					
	Hot-Zone Seals 1	Luted Seals 2	Resilient Seals 3	Inflatable Seals 4	Contact Seals 5	Noncontact Seals 6
(1) Temperature Tolerance? (At a 200-300 C (400 to 600 F) Operating Level?)	■*	■*	☐	☐	■	■
(2) Heat Excursion Tolerance? (Withstand 430 C (800 F) for Short Periods Without Destruction?)	■	▨	XXX	XXX	■	■
(3) Increased Gap-Closure Capability? (Can Close a 12.7 mm (0.5-inch) Inward Bow on a Warped Jamb?)	▨*	▨*	☐	■	■	XXX*
(4) Automatic Gap-Closure Capability? (No Manual Adjustments?)	▨	▨	?*	■	■	☐
(5) Resistance to Corrosion and Chemical Attack? (Withstand Heated Solvents, Tars?)	■*	■	■	☐	■	■
(6) Total-Failure Proof? (Unsusceptible to Sudden Failure?)	?	▨	▨	XXX	■	■
(7) Avoids New Cleaning Problems?	?	▨	☐*	☐	■*	▨
Evaluation Summary Based on Technical Specifications	?	▨	☐	XXX	■	XXX
Summary Rating		Possible	Unlikely	Not Possible	Probable	Not Possible
Functional Requirements in Question Form						
(8) Retrofitable?	?	▨	■	▨	■	▨
(9) Compatible with Existing Working Machinery?	?	▨	■	▨	■	▨
(10) Operable and Reliable Commensurate With Existing Seals?	▨	▨	☐	☐	■	▨
(11) Dependable and Repeatable?	?	?	☐*	☐	■	■
(12) Avoids Any Additional Environmental Problems?	?	▨	▨	▨	■	■
(13) Avoids Adverse Effects on Product Quality?	■	■	■	■	■	▨*
Evaluation Summary Based on Functional Requirements	? Unknown	▨ Possible	☐ Unlikely	☐ Unlikely	■ Probable	▨ Possible
OVERALL EVALUATION Level of Confidence in Successful Future Development and Performance	? UNKNOWN	▨ POSSIBLE	☐ UNLIKELY	XXX NOT POSSIBLE	■ PROBABLE	XXX NOT POSSIBLE

The four other concept families were given essentially low ratings. It is suggested that these concept families be re-evaluated if the temperatures of the end closures are lowered (or if a company elects to test water-cooling of the equipment) and if new heat-resistant materials become available.

Contact Seals (Rating: High Probability of Successful Development and Performance

The contact-seal concepts shown in Chapter VI (pages VI-40 to VI-53) all emphasize seal-element mechanical flexibility in one way or another. The objective of this flexibility is to enter and seal sections of jambs having a degree of inward bowing that cannot be sealed by existing seal elements. Statistical information on the range and distribution of jamb-distortion measurements across the coke-producing industry are not available. However, the measurements given below in Table VII-6 (taken from Figure IV-21, page IV-40) are believed to be an example of the upper limit or maximum level of distortion to be expected. This belief is based on the high level of door emissions being encountered by the company that supplied these data.

It is possible to consider a flexible metal seal that would conform automatically to the indicated gross distortion range of from -0.69 to +0.28 inch, or a total range of about 1 inch (about 25 mm). This, however, is regarded as being impractical in terms of probable costs/benefits determinations. The specifications, therefore, were lowered to a maximum of 16/32 inch (12.7 mm) for an inward jamb bow and 8/32 inch (6.3 mm) for a maximum outward bow. Even these specifications are believed to be on the high side of the majority requirements.

All of the flexible seals shown in the contact-seal family of concepts assume that (a) the seals will be "loaded" by deflecting the seals against the jambs as the doors are mounted on ovens, and (b) there will be no need for helper or auxiliary springs. The amount of deflection of the corners of the spring seals will depend upon the setting of the corner stop-bolts on the doors. Ideally, door-stop settings should be uniform for every door on a battery. This, however, requires a rather large amount of allowable flexibility in the

TABLE VII-6. RANGE OF JAMB DISTORTION MEASURED ON EIGHT JAMBS AT A BATTERY HAVING SERIOUS DOOR-EMISSIONS PROBLEMS

(Results are presented in 32nds of an inch measured inward (-) or outward (+) from a straight line drawn between the upper and lower jamb corners.)

Jamb Number	Maximum Directional Distortion Per Jamb Side				Maximum Directional Distortion Per Jamb		Maximum Total Horizontal Displacement		
	Left Side		Right Side						
	(-)	(+)	(-)	(+)	(-)	(+)	In 32nds	In Inches	In MM
1	5	0	0	8	5	8	13	0.41	10.4
2	1	0	1	5	1	5	6	0.19	4.8
3	22	0	12	0	22	0	22	0.69	17.5
4	12	0	10	4	12	4	16	0.50	12.7
5	5	0	0	6	5	6	11	0.34	8.6
6	0	7	0	8	0	8	8	0.25	6.35
7	11	0	15	0	15	0	15	0.47	11.9
8	0	6	0	9	0	9	9	0.28	7.1
All Jambs	-22/32	+7/32	-15/32	+9/32	-22/32	+9/32			
					-0.69 inch	+ 0.28 inch	Average	0.39	9.9

spring-seal element. For example, if the specification distances for both inward and outward bowing occur on the same side of a jamb, then the maximum seal deflection required is 19 mm (0.75 inch).

This 19-mm deflection of a seal could be set as a development target, but there is no evidence that any extreme combination of inward and outward bowing exists on any one jamb. If, on the other hand, the seal-deflection limit were set at 13 mm (0.5 inch), then with door-stop adjustments, 7 out of the 8 jambs previously described could be sealed. As one example, the door-stop setting on Jamb 4 (in Table VII-6) could be set at 10 mm (3/8 inch) at all four corners. Then a maximum seal deflection of 13 mm (1/2 inch) would accommodate both the inward and outward (3 mm) distortion on this jamb. This is considered only a minor deviation from the specification that there be no need for manual adjustment of upgraded seals.

Taking the view that the example jambs are upper-limit examples, it was decided to set a 13-mm (0.5-inch) seal deflection as a practical requirement in the following spring calculations. This represents a deflection distance four times that considered possible in the existing spring-type seals, and would probably seal the vast majority of existing coke-oven doors.

Some of the contact-seal concepts have the flexible seal angled toward the door plug (pages VI-44 and -45), and some seals are angled away from the door plug. Internal pressure in the oven will attempt to push the latter type away from the jamb in a minor way. For a peak pressure of 100 mm (4 inches) of H_2O at the bottom of the seal on an oven, the internal pressure on the seal is about 0.96 KPa (0.14 psi). To compensate for this back pressure, it is estimated that it will be necessary to have a minimum contact pressure of 0.18 kg/cm (1.0 pound per linear inch) at the bottom of an inward bow. This would require an additional corner deflection of only 0.5 mm (0.02 inch) for most of the spring seals that can be considered for this application. Because this is only a minor increase in required deflection in the jamb corners, the effect of internal pressure was disregarded in the following calculations.

The amount of force required to mount future doors, to the point where the door-stops seat on the jamb, will vary depending on the spring-seal configuration, the spring thickness, the amount and direction of distortion of the jamb, and other considerations. With highly flexible sealing elements, the mounting force is expected to be much lower than present mounting force. It is probable that with more-flexible sealing elements, doors will be latched with only enough force to seat the corner stops. Calculations of the expected effective latching force are included in the following paragraphs.

Example of Spring-Seal Calculations. Because one of Battelle's major recommendations centers on the development of more-flexible and (more-heat-resistant) metal-seal elements, a simplified example calculation was completed to judge the feasibility of this approach.

The purpose of this feasibility calculation is to estimate the probability that sufficient required mechanical deflection (13 mm) can be achieved (within reasonable bending-stress limits) with a spring thickness that will be capable of resisting both abuse and thermal stresses.

There is a wide choice of types of springs that can be considered for this application. Some of these are:

- Simple cantilever spring (parabolic shape).
- Tapered-end cantilever springs (ends tapered to achieve a circular arc).
- Constant-strength cantilever springs (thickness tapered toward the loaded end).
- Leaf springs (shown on pages VI-48 to -52).
- Curved-end cantilever springs.

The last four types of springs listed above are designed to achieve an increased amount of deflection for a given limit of allowable bending stress. Of these types, Battelle researchers elected to evaluate feasibility using a single, curved-end cantilever spring of constant cross section. This type of spring is shown in Figure VII-2. This figure also shows the full-scale dimensions of the gas passage in one type of door/jamb relationship into which a spring seal is to be fitted. For calculation purposes (and as shown in Figure VII-2), the curved-end spring is taken to have a 3-inch straight section and a 1-inch radius on the curved section. The effective length of the spring is 6.14 inches (from the loaded end to the point where the spring is fastened).

The basic equations for deflection and maximum bending stress for curved-end cantilever springs are taken from Alexander Blake's article in Machine Design, July 23, 1959, page 151. These equations in U. S. units are as follows:

$$\begin{array}{l}\text{Spring-End}\\ \text{Deflection}\\ \text{(Inches)}\end{array} = \frac{\begin{array}{c}\text{Load on Spring End (lb) x}\\ \text{(Radius of Curved End-In.)}^{3}\text{ x Constant}^{*}\end{array}}{\text{Modulus of Elasticity (psi) x Moment of Inertia (in.}^{4}\text{)}}$$

$$\begin{array}{l}\text{Maximum}\\ \text{Mechanical}\\ \text{Stress (psi)}\end{array} = \frac{\begin{array}{c}\text{6 x Load on Spring End (lb) x}\\ \text{Effective Spring Length (in.)}\end{array}}{\text{Spring Width (in.) x (Spring Thickness, in.)}^{2}}$$

For the purpose of this example calculation, the maximum allowable bending stress was taken to be half of the yield strength of any candidate high-performance spring material at 320 C (600 F).

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[*] This constant is taken from a table in Blake's paper. The constant varies with the magnitude of the ratio of the straight portion of the spring length to the radius of the curved end.

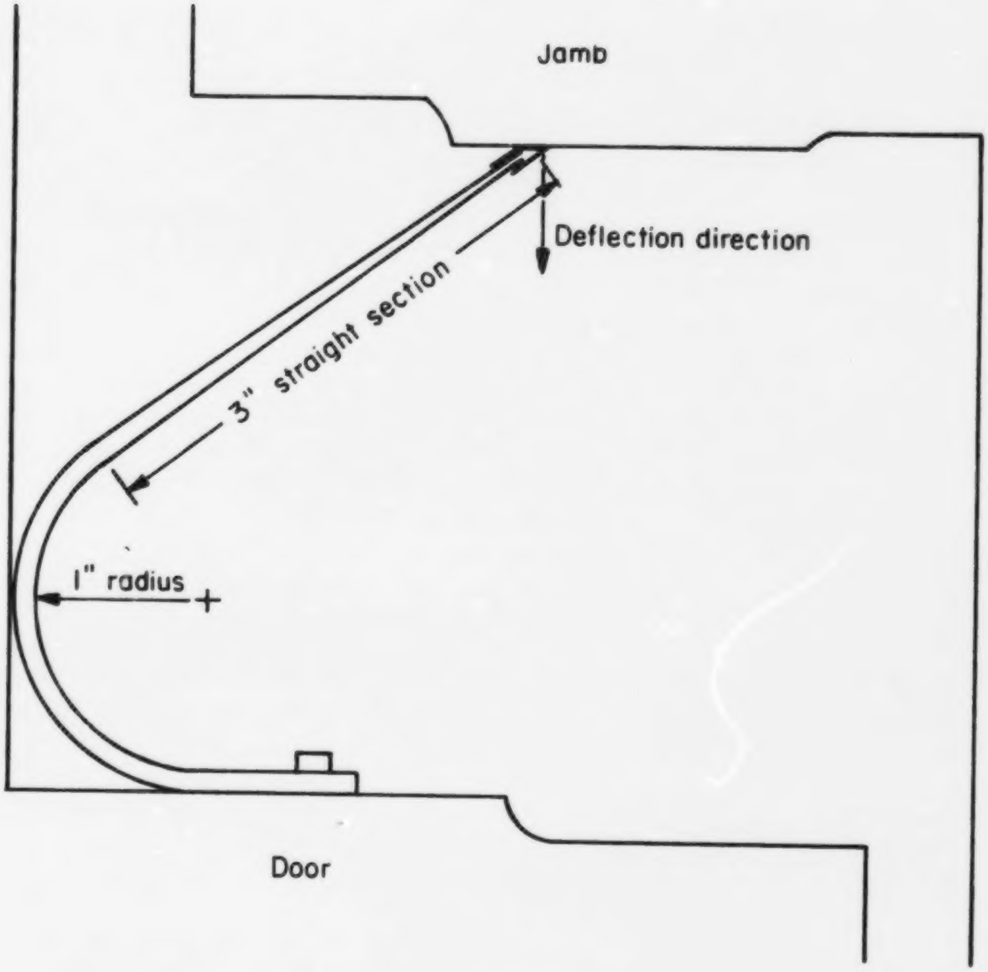

FIGURE VII-2. FULL-SCALE CROSS SECTION OF A GAS-PASSAGE AREA SHOWING THE INSTALLATION OF AN EXAMPLE CURVED-END CANTILEVER SPRING SEAL

Age-hardened Incoloy Alloy 903 has a yield strength of 150,000 psi at this temperature. Many alloys (including iron-based superalloys) have equivalent or higher yield strengths at this temperature. Data for Incoloy Alloy 903 were used in the following calculations primarily because of this alloy's low coefficient of thermal expansion. This characteristic has no effect on the deflection performance of a spring, but it is very favorable in terms of lowering the thermal stresses in springs operated in heated applications. The importance of a low thermal expansion is discussed in later paragraphs.

Assignment of a maximum allowable mechanical stress of only 75,000 psi is a conservative approach. However, many other factors must be considered, such as spring relaxation, creep under load, etc. Selection of a relatively low stress limit minimizes these other problems.

Assumptions. In the spring-seal calculations, the assumptions (along with some comments) are as follows:

(1) The curved-end spring data are:

- Effective length of spring (contact point to fastening point) is 6.14 inches.
- Length of the straight portion of the spring is 3.0 inches.
- The radius of the curved end is 1.0 inch.
- The constant (in the deflection equation) is 50, as taken from Blake's paper.
- The spring thickness is a constant over the length of the spring.

(2) To simplify the calculations, the width of the spring seal is taken to be 1.0 inch. In practice, the width of the spring will be about equivalent to the height of the jamb.

(3) Maximum allowable mechanical bending stress is 75,000 psi (fiber stress).

(4) It is assumed that elementary beam-deflection theory for small deflections is also correct for "large" deflections. The deflections being considered in the

subsequent calculations are large deflections. In practice, springs with a large ratio of width to thickness have an increased flexural rigidity over and above those calculated. On the other hand, a spring being subjected to a large deflection is more flexible than calculated. It will require a detailed analysis to relate these factors for curved-end springs, but if simple cantilever springs of constant thickness were used in this application, the large ratio of width to thickness (jamb height/spring thickness) would increase flexural rigidity about 10 percent*. On the other hand, the large deflection (say 13 mm or 0.5 inch) would decrease spring rigidity by 30 percent or more. Overall, it is expected that the spring seals will be more flexible, per unit of stress, than calculated. Simple cycling-bending test equipment has been developed for characterizing the mechanical properties of spring materials, including high temperature performance.**

(5) The modulus of elasticity is taken at 21,800,000 psi at 320 C (600 F). Many alloys have a modulus at this temperature in the range of 24,000,000 to 26,000,000 psi. Changes in modulus, however, have only a minor effect on spring thickness.

(6) Spring-seal deflection due to the internal gas pressure against the back side of the seal is disregarded.

(7) Distortions (in or out) on the jamb are all gradual; i.e., there are no abrupt changes in distortion along the height of the jamb. The maximum change expected is about 4.3 mm (0.17 inch) inward deflection per foot of jamb height.

(8) Sealing can be effected by metal contacting the residual jamb deposits, even at low contact pressure.

(9) Seal deflection is directly proportional to the load on the end of the spring.

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* Wahl, A. M., Mechanical Springs, McGraw-Hill Book Co., 1963.

** Weissman, G. F., Wonsiewicz, B. C., "Characterization of the Mechanical Properties of Spring Materials", Journal of Engineering for Industry, August, 1974.

Using the two foregoing equations, various calculations were made to show the relationships and trends among four interrelated elements. The results are presented in Table VII-7. Only those results within the boundaries of interest are shown.

The example calculations indicate that:

(1) From a mechanical viewpoint, it is highly probable that a spring sealing element can be developed to deflect 13 mm (0.5 inch) and still have a thickness that will resist being damaged. This deflection can be accomplished without exceeding a mechanical bending stress of 75,000 psi.

(2) As would be expected, large deflections (0.75 inch) with this simple type of spring (within the space limitations described) require very thin seal elements. Also, thin springs cannot exert much contact force on the jamb.

(3) If the maximum required deflection on the door seals of all the ovens on a battery is less than 13 mm (0.5 inch), the deflection distance (doorstop setting) can be lowered with a proportional general decrease in the bending stress level in the seal elements; i.e., the design safety factor would be increased.

Calculations 11 through 15 in Table VII-7 were made to estimate the total spring-loading force required for individual doors. Along any warped jamb there will be a variation in the contact force at the seal depending on the incremental deflection of the seal. On a perfectly straight jamb with assumed dimensions of 0.6 x 3.6 m (2 feet by 12 feet), a 13-mm (0.5-inch) deflection of the seal at each corner with a 2.8-mm (0.111-inch) thickness of curved-end spring seal would require a minimum door-latching force of 3810 kg (8400 pounds). On a jamb with considerable inward bowing, the required minimum door-latching force would be decreased. For example, Jamb 7 in Table VII-6 has a maximum inward bowing of 8.7 mm (11/32 inch) on the left side of the jamb and a maximum 11.9 mm (15/32 inch) inward bowing on the right side. The average amount of inward bowing is about 3.7 mm (1/8 inch, 0.147 actual). Under these conditions the required latching force is 2676 kg (5900 pounds) with a 13-mm (0.5-inch) seal-element deflection in the jamb corners. The range of

TABLE VII-7. SUMMARY OF EXAMPLE SPRING CALCULATIONS

Calculation Number	Selected Spring Deflection		Selected Unit Loading		Calculated Spring Thickness		Calculated Bending Stress	
	MM	Inch	KG/CM	Pounds/ Linear Inch	MM	Inch	kPa	Psi
1	10.2	0.40	0.9	5	1.8	0.070	259,000	37,600
2	10.2	0.40	1.8	10	2.2	0.088	328,000	47,600
3	10.2	0.40	3.6	20	2.8	0.111	413,000	60,000
4	10.2	0.40	6.2	35	3.4	0.135	487,000	70,700
5	12.7	0.50	0.9	5	1.6	0.065	300,000	43,600
6	12.7	0.50	1.8	10	2.1	0.082	378,000	54,800
7	12.7	0.50	3.6	20	2.6	0.103	479,000	69,450
8	12.7	0.50	4.5	25	2.8	0.111	517,000	75,000
9	19.0	0.75	0.9	5	1.4	0.057	391,000	56,700
10	19.0	0.75	1.8	10	1.8	0.0715	496,000	72,000
			Calculated Unit Loading		Selected Spring Thickness		Calculated Bending Stress	
11	12.7	0.50	4.5	25	2.8	0.111	517,000	75,000
12	10.2	0.40	3.6	20	2.8	0.111	413,000	60,000
13	5.1	0.20	1.8	10	2.8	0.111	207,000	30,000
14	2.5	0.10	0.9	5	2.8	0.111	103,500	15,000
15	0.5	0.02	0.2	1	2.8	0.111	21,000	3,000

contact pressure in this instance would be 4.5 kg/cm (25 pounds per inch) across the top and bottom of the jamb decreasing to 0.28 kg/cm (1.6 pounds per inch) at the bottom of the jamb section bowed inward 11.9 mm (15/32 inch).

Thermal Stresses and Thermal Buckling. As noted in Chapter IV, there is some evidence of thermal buckling on the upright sealing edges of one type of existing seals. This buckling is believed to be due to excessive stress resulting from the restraint of the thermal expansion of these seals. These seals are all bolted into place on the doors at ambient temperature and are then placed against heated jambs. There is also a possibility of concentrated mechanical loading at the point of buckling, which would further contribute to buckling.

It is not possible to analyze the thermal-stress aspects of the present and upgraded metal-to-metal seal designs without getting detailed field data (temperatures and strain measurements) and completing an analysis and modeling program. However, some general comments can be made about thermal stresses and thermal buckling in spring-seal elements. For example, for a given thermal stress, the ability of restrained sheet material to resist buckling is a function of the square of the thickness. Doubling the thickness will increase the resistance to buckling by a factor of four. Therefore, thin sealing strips are to be avoided.

In the comparison of different metals and alloys, a lower thermal stress is favored by a low coefficient of thermal expansion, a higher thermal conductivity (a lower temperature gradient for the same geometry), a lower modulus of elasticity, and a larger number for Poisson's Ratio. One form of equation used to evaluate thermal stress is as follows:

$$\text{Thermal Stress} = \frac{\text{(Coef. of Thermal Expansion)} \times \text{(Thermal Gradient)} \times \text{(Mod. of Elasticity)}}{2\text{(1-Poisson's Ratio)}}$$

In the preceding spring-deflection calculations, it was found, as an approximation, that a 2.8-mm (0.111-inch)-thick strip of age-hardened Incoloy Alloy 903 could be selected for a spring material to reach a required 13-mm (0.5-inch) deflection. Presently some of the existing spring-type seals are using 3-mm (1/8-inch)-thick austenitic stainless steel strip. A comparison of the mechanical and thermoelastic properties of Alloy 903 and Type 304 stainless steel (as one example of austenitic stainless steel) is as follows:

	Alloy Designation			
	Incoloy Alloy 903, Age-Hardened		Type 304 Stainless Steel, Cold-Worked	
Yield Strength (0.2% Offset) at 320 C (600 F); MPa (psi)	1034	(150,000)	Up to 827	(120,000)[*]
Coefficient of Thermal Expansion; 10^{-6}cm/cm/C (10^{-6} in./in./F)	2.67	(4.0)	6.40	(9.6)
Tensile Modulus of Elasticity; GPa (10^6 psi)	150	(21.8)	172	(25.0)
Poisson's Ratio	0.23	(0.23)	0.32	(0.32)
Thermal Conductivity; Watt/mK (Btu/hr/Ft^2/in./F)	1.56	(130)	1.53	(128)

Introducing these data into the thermal-stress equation and solving indicates that under identical conditions of heat input and mechanical restraints, the 3.2-mm (0.125-inch)-thick stainless steel will develop a 3.5 times higher internal stress than 2.8-mm (0.111-inch)-thick Alloy 903 strip. That is, Alloy 903 will develop only about one-third of the thermal stress, and will be able to tolerate three times more stress without failure.

The properties of Incoloy Alloy 903 are unusually favorable for minimizing thermal stress, but it is known that many other alloys that can be considered for this application develop significantly lower thermal stress than austenitic types of stainless steels. In addition, there are alloys that can tolerate a significantly higher stress than austenitic stainless steels. The final selection of the spring-seal material must include consideration of numerous factors including creep and relaxation characteristics, fabrication costs, and material availability. In addition, it is possible to lower the thermal stress level by design considerations. For example, if the spring-seal element is permitted some thermal-expansion movement, particularly in the door-height direction, the thermal stresses would be lowered significantly. This, in turn, would permit consideration of other classes of alloys.

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[*] This is a handbook value for very severely cold-worked Type 304 stainless steel. It is estimated that the actual yield strength of the austenitic stainless being used on existing seals is in the 275 to 414 MPa range (40,000 to 60,000 psi). Alloy 903 would then have a 2.5 to 3.75 times higher yield strength than the stainless steel in existing seals.

Feasibility Summary Statements. The general approach of developing upgraded and retrofitable metal-to-metal contact seals that will minimize emissions is feasible. The reasonableness and probability of success of the contact-seal concept are high. Battelle does not, however, recommend that an attempt be made in only one step to design an upgraded seal (or jamb) and then subject it to performance and endurance trials. Instead, it is suggested that more fundamental information and analysis are required before design should begin. In addition, Battelle recommends a program consisting of mathematical and physical modeling prior to designing a full-scale test unit. For example, it will be necessary to evaluate the stress considerations in the seals at the corners of doors. The interest in the full-scale unit would be both in its sealing performance and in its dimensional stability relevant to existing equipment. With this approach, there should be no need to complete an endurance check of the test equipment prior to starting the retrofit of existing coke-oven doors. Early physical measurements completed on full-scale test units will determine whether the goal of dimensional stability has been achieved.

It should also be noted that Battelle is not recommending the curved-end cantilever spring seal for coke-oven doors. This geometry was only an example selected for the purpose of completing preliminary calculations. The entire contact-seal family of concepts (with additions) should be evaluated prior to making a selection of seal geometry.

Other Comments on Contact Seals. Various representatives of the AISI Task Force have expressed concern about (a) the problem of cleaning of some of the contact-seal concepts and (b) how resistant such seals are to abuse and damage. Some of the aspects of cleaning are discussed in Chapter IV. It is expected that the cleaning of upgraded metal-to-metal seals will not be more difficult than with the present seals. In some instances it may be necessary to develop variations and improvements on the present cleaning methods to accommodate some contact-seal concepts, but it is not forseen that this will present any particular problem. The important considerations are to clean the tar from the bottom of the gas passage on every cycle and to remove any coal that may have fallen into the gas passage.

The ability to withstand abuse is more a function of the toughness of the seal material than other considerations. Abuse (such as striking the jamb hooks with the sealing edge) can be eliminated by upgrading the door-spotting equipment and procedures. Laboratory tests will indicate whether reinforcement is required in the areas where workers use hand tools for cleaning the gas passage.

Luted Seals (Rating: Possibility of Successful Development and Performance)

In hindsight, Battelle's use of the term "luted seals" could more appropriately be described as the use of sealants foamed in place on the jamb or door before a door is mounted, and foaming or other materials that are injected into the gas passage or into a special channel after the door is mounted on the oven.

The only possible way to evaluate and/or bypass the uncertainties of this general approach would be through a laboratory testing program or through a combined laboratory and coke-plant testing program. As previously noted, all Battelle evaluators have reservations on various aspects of foam sealing, and have reservations particularly in terms of confidence that all of the specifications and functional requirements eventually can be met.

Rigid and resilient foamed materials consist of a mass of gas bubbles trapped in a rigid or resilient matrix. Many types of plastic materials (and some inorganic materials) are commercially available in foam form. These materials can be produced in either an open-pore or closed-pore form. Some of the polymer materials char rather than melt when exposed to high temperatures. Phenolic foam is one example. Generally, the manufacture of foams consists of mixing of selected liquids (including a gas-forming agent) and injecting the mixture into a mold. Depending on the type of foam, the mold can be either hot or cold. With the immediate action of the gas-producing agent, the material swells rapidly to fill the mold. Once fully expanded, the foam is solidified by either internal chemical reactions (polymerization, often exothermic in nature), by heat curing, or by hydration (as for inorganic materials). In some instances, the foam can be generated mechanically by injecting gas from a separate source.

In concept form, it is possible to visualize the injection of a foamable liquid into a hot gas passage after the door is on the oven. Within a minute or two, the injected liquid could (in theory) foam and fill the entire gas passage area with a closed-pore foam. Additionally, the foam could fill much of the space between the door plug and the oven walls. If this foam could be rapidly stabilized and would only char when heated (rather than melt) the present flow of dust, tar, and volatiles to the metal sealing area would be minimized. The unknowns are many, including (a) the possible problems in removing the foam materials after a completed cycle, (b) lack of information on which foamable materials will resist the coal-tar chemicals and the temperatures to be encountered, (c) whether there will be an outward movement of gases to a leaking metal seal along the interface between the foam and the coke-oven wall, and (d) how much foam would leak out (before solidification) between the present gaps between the metal seal and the jambs. The resistance of foamed materials to coal-tar chemicals and coke-oven temperatures could be tested in operating ovens. The possible leakage of gas past the foam sealant, and the level of leakage of foam through gaps, could be determined in laboratory equipment.

The use of commercial foamable plastics can be expensive in this application when it is taken into consideration that a door is mounted about 500 times a year and there are over 25,000 doors. In the evaluation of this concept family, Battelle researchers assumed that a low-cost foaming material would be developed for this application, and that the use of the foam would not introduce any additional environmental problems. As a possible example, it was noted that asphalt has been used to produce a rigid closed-pore foam (U. S. Patent 2,901,469). If asphalt can be foamed, it is thought that perhaps coal-tar pitch can be foamed. It is not known whether a coal-tar pitch foam can be cheaply and rapidly solidified once it has been foamed in place, or whether the stabilized foam would melt (rather than char) upon being heated. In a related application, the Porter Paint Company (Louisville, Kentucky) sells a coal-tar epoxy as a coating material that solidifies after application.

In evaluating the potential for success of developing effective foam sealants for (a) use between the door jamb and the mating surface on the coke door and (b) use in the gas passage inside of doors, Battelle's final consensus was to consider only sealants between mating metal surfaces. The major negative judgment against gas passage seals was that the effectiveness of the internal seal would still depend upon the effectiveness of the existing metal seals. A gap in the metal-to-metal sealing arrangement would encourage leakage of emissions past the foam sealant. This same reasoning was also used to downgrade the rating of the hot-zone concept family. It is for this reason that no discussion of hot-zone sealing is included in this chapter.

It was judged, however, that there was considerable potential for a successful development for those concepts that placed a suitable sealant (foamed or unfoamed) between the jamb and a retrofitted mating plate on the door before the door is mounted. The final evaluation of this approach is the one shown in the foregoing summary Table VII-6. In this table reservations are noted as to whether an approach can be developed to accommodate jambs that are severely bowed. Also, it is not known whether it would be possible to avoid new cleaning problems, and whether the procedure would be truly dependable and repeatable.

It is recommended that the concept of placing a sealant between the jamb and a fixed door plate (as shown on pages VI-11 to -14) should be studied in an experimental research program. It should be noted, however, that in most instances Battelle researchers assumed that a steel fixture would be mounted on warped jambs to (a) present a straight surface to the door plate and (b) hold the sealant material. Further consideration of this approach, however, goes full circle into considering a fixture on the jamb to present a straight surface to the existing seals and again introduces concerns as to whether an overlay plate would promote or retard continued jamb warpage. Therefore, it is judged that any research program on sealants should be directed to being effective with existing jambs. This is the major reason for the interest in swelling sealants - to close gaps.

Considering the fact that any sealant held between the jamb and the mating plate on a door will be heated in air, it is to be expected that the sealant will harden. With most organic foam materials, it is probable that upon being heated the material will release emissions into the atmosphere. To bypass this possible environmental problem, it is necessary to consider inorganic materials for this application. (The use of filled phenolic foam may be an exception to this judgment.)

The fact that the sealant will harden during one cycle is not considered detrimental, provided the material remains under compression and does not crack, deteriorate, or adhere to or corrode the metal parts. Possible sealants for this application are foam concrete, gypsum foams, and some foam-clay refractories using a mixture of clay and gypsum. In some instances, these materials are available commercially*, and they have been sprayed on vertical surfaces. However, these are all water-based. This introduces concern for thermal shocking the gray iron jambs. In this regard, it should be noted that wet mud slurries are presently being hand plastered against the outside of gray iron jambs and door frames on some older ovens that are in operation. Here again, it is noted that the drop in the surface temperature of a jamb on meeting a wet sealant can be measured and the thermal stresses can be calculated.

The chuck doors on the pusher side of batteries might serve well as experimental stations for the evaluation of sealants.

Resilient Seals (Rating: Unlikely to Result in Potential Successful Development and Performance)

This family of concepts is evaluated as unlikely in terms of potential successful development. Shortcomings appear in meeting the specifications on (a) acceptable tolerance for normal operating temperatures (water cooling not considered), (b) gap-closing ability, and (c) conformity to standard cleaning methods.

At 320 C (600 F) and higher, polymerized materials lose weight slowly, become soft or brittle, and generally change in characteristics with time. The advantages of "high-temperature plastics" are mainly in low rates of deterioration at high temperatures when compared with conventional plastics, but the high-temperature plastics still deteriorate.

In the search for suitable nonmetallic sealants and materials, Battelle considered many commercial elastomeric (rubber-like) materials and reinforced high-temperature resins. The interest in the reinforced resins at one time was in the possibility of using this fairly flexible type of material as a substitute for the relatively stiff steel beam used to hold the metal sealing edge on the existing fixed-edge design of seal. As one example, Monsanto was contacted for information on their Skybond 703 product, a high-heat-resistant resin which when reinforced with fiber glass has "excellent strength retention up to temperatures of 350 C (650 F)". Discussions indicated that the supplier did not expect retention of properties at 320 C (600 F) for 2000 hours (about 3 months) or even less time. This same response was obtained from other companies and from research laboratories developing high-temperature plastics for the aerospace industry.

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* Rivkind, L. E., "Improved Technology for Rigid Inorganic Foams", Journal of Cellular Plastics, July, 1967, p. 329.

The present operating temperatures of jambs (and metal seals) are above the practical limits of elastomeric and resin materials, if these materials are to be pressed against heated jambs for long periods of time. This introduces consideration of lowering jamb temperatures via either jamb insulation and/or water-cooling, in one configuration or another. Water-cooling should be considered for the jambs of new coke-oven battery installations, but present a difficult and expensive problem when considered for retrofit applications. Battelle rates retrofitable water-cooling for jambs on existing ovens as an approach of "last resort"; i.e., the approach to use if and when other approaches are proven to be insufficiently effective.

Some coke-oven plants have tested Teflon as a potential sealing material; i.e., as a secondary sealing system positioned either inboard or outboard of the existing metal seal. Teflon-coated asbestos has been mounted alongside the upstanding edge of the existing seals in such a manner that the Teflon material would contact the jamb prior to the contact of the metal seal. This is in effect an attempt to (a) increase the gap-closing capability of the overall sealing system and (b) obtain a better seal because of the ability of compressible materials to deform and fill the asperities of the mating surfaces. From the viewpoint of chemical inertness, Teflon is the best choice to resist chemical attack. It is rated as being "stable" up to 260 C (500 F) which is, however, a lower temperature than jambs reach at the top of the oven. Also, the pressing of Teflon against a heated jamb acts to insulate the covered portion of the jamb and further increases the contacting surface temperature of the Teflon. The most ambitious effort in this regard, and on which information is available, was to equip all the doors on a battery with outboard seals of Teflon-coated, asbestos-cloth tubing having Monel fibers in the tubing to provide resiliency. The early results of this test program were encouraging in terms of emission control, but, overall, the results were not successful because of the deterioration of the expensive tubing and because it was not possible to clean the tubing by conventional scraping methods.

If effective resilient-seal materials were available, consideration would be given to either mounting the material as a guard seal (on the existing metal seals) or developing a single seal based only on the resilient material. It is doubted that a resilient material by itself can close the major inward bowing on some jambs. In this instance, it would be necessary to design a more flexible metallic holder for the resilient material. Seal retainers or holders could be designed to provide the extra flexibility required, but, then, the resilient material would not be required.

Inflatable Seals (Rating: No Possible Application)

This concept family has appeal because (a) it would be a gas-tight seal and (b) the inflatable rubber-type tubes are not expensive. However, as indicated in Table VII-5, the drawbacks of this approach are many if water cooling and inert-gas back-pressurizing are not included as part of the system.

The original interest in feeding of inert gas into the gas passage between an inflatable seal and the standard metal-to-metal seal was to prevent coal-tar volatiles from reaching the inflated tubes. Discussions with steel-plant technical personnel working in the by-products departments of coke plants have indicated that all elastomers are attacked by coal-tar volatiles in one way or another. Research is in progress in this field by material manufacturers, but discussions with these companies indicated that they will not recommend even the most volatile-resistant product (trade name Chemigum) for this application. It had been suggested that the inflatable-tube material be coated with Teflon, but no tube manufacturer indicated that this could be done.

To avoid the need for disconnecting and connecting the feed line for the inflating gas every time the coke door is opened and closed, the most logical place to install an inflatable tube seal is on some part of the door jamb. This, however, presents a problem in protecting the bottom portion of the tube from the hot coke during and following coke pushing.

Battelle researchers do not foresee any possible application of inflatable seals on coke-oven doors.

Noncontact Seals (Rating: No Possible Application)

In general, the noncontact family of sealing concepts depends on the injection of pressurized gases into the seal area to prevent the outward flow of emissions. Labyrinth seals, in which intimate contact between mating members is not essential, were considered. The pressure of gas injected within the labyrinth would exceed the gas pressure in the oven. Thus, the sealing gas would leak into the oven, as well as out into the atmosphere. It was concluded that this approach would be feasible only for jambs that had only a minor degree of warpage; i.e., for jambs that can already be sealed by existing designs. This family of concepts was given a rating of "not possible" primarily because it does not have increased gap-closure capability over and above the existing systems.

Any approach that injects back-pressurizing gas into the seal area of coke-oven doors will release some of this same gas into the atmosphere through gaps in the primary or existing sealing system. Where the gaps in the primary system are large, even the idea of using an inert gas (such as nitrogen) as a "sealant" does not appear to be practical. However, there is an interest at Battelle in considering coupling back-pressurizing with tight primary seals. The interest in this instance is in finding out whether this approach minimizes the cleaning effort presently required on door plugs, jambs, and seals. It is understood that some experimental work of this nature has been done in Europe, but details are not available. Battelle researchers suggest that a study should be completed in which (a) the back-pressurizing gas is injected behind the jamb (not through the door), and (b) the gas passage on the door and the space between the plug and the door are restricted at the top of the oven to force a portion of the back-pressurizing gas into the coal. As noted in Chapter IV, any procedure that eliminates the deposition of tar on the jamb will result in outward gas leakage past a metal-to-metal seal. It is expected that any back-pressurizing system will not eliminate deposition of all tars on jambs. However, if it decreases the outward flow of tars significantly, it should decrease the cleaning problem. From this viewpoint, Battelle researchers consider this approach worth testing.

CHAPTER VIII

DEVELOPMENT OF AN EMISSION EVALUATION METHOD

To aid in developing improved coke-oven end seal, it is desirable that a method be available to demonstrate improvement and to measure the degree of improvement. Therefore, as part of the overall research program, a task was established with the objective of developing a method for quantitatively measuring door-seal particulate emissions.

Comments on the Measuring Method

The emphasis in this phase of the research was on weighing the particulate emissions collected over time on a 3.15 x 3.94 cm (8 x 10 inch) glass-fiber filter. The filters were obtained from Mine Safety Appliance Company and had the designation 935-BJH J-1453 (46-26-Natural). These filters are listed as having a collection efficiency of over 99 percent for particle sizes of 0.3 micron and larger.

It was decided that performance of coke-oven door seals could be evaluated best through a comparison of the quantity of particulate matter that escapes from around the door during the first few hours of the coking cycle. In most instances, ovens tend to seal themselves within the first hour or two of the coking cycle — even those ovens that are considered to be leaking badly early in the cycle.

After a review of literature dealing with tests that have been run on coke ovens, and consideration of various approaches suggested by Battelle staff members, the idea of a sealed hood was selected. Although this method has some inherent disadvantages, it does lend itself to a quantitative measurement of coke-oven door leakage.

The initial basic idea was to seal off an oven door by placing a cover or hood over the buckstays and sealing between the buckstays for the total height of the oven doors, except for a controlled air inlet at the bottom of the hood and an exit at the top. A metered supply of clean air would be drawn into this space between the buckstays, and would sweep up over the door and out through a duct connected to the blower. A high-volume sampler could then be attached to the duct at the top to draw off a known amount of gas which would be passed through the sampler's filter to collect the contained particulate matter for weighing.

Initially, consideration was given to drawing air into the bottom of the hood through a charcoal filter. As air was drawn into the space beneath the hood, particulates and other matter from adjoining ovens would be filtered out by the charcoal. Thus, unpolluted air would be mixed with the gases leaking from around the door. Because of lack of clearance between the buckstays and the coke guides or pusher machines, it was necessary to abandon this idea. Instead, the bottom of the hood was completely sealed off between the buckstays. Air from a filtered compressed-air line was then piped into the space between the buckstays for release near the bottom of the door.

Discussion of Equipment and Procedure

So that the hood could be readily transported and put in place, it was made of aluminum sheets about 1.1 meters wide by 0.9 meter high (42 x 35 inches). These sheets were fastened together with hinges; five were the full 0.9 meter (35 inches) high and one was about 0.4 meter (16.5 inches) high. The hood could be carried by one man as it weighed only about 18 kilograms (40 pounds).

Figure VIII-1 shows a man holding the hood prior to installing it on the buckstays of the simulated coke-oven end built in the laboratory. The shiny surface is the aluminum backing of glass-fiber insulation placed on the outside surface of the hood to minimize heat loss and thereby avoid excessive condensation on the inside surface.* This simulated coke-oven end was used to assemble, evaluate, and try out the sampling equipment before taking it to an operating coke-oven battery. The simulated oven end was built of plywood, with metal strips attached to the simulated buckstays for attaching the hood magnetically.

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* During the field testing of this equipment it was found that the insulation of the hood was not required or desirable.

Figure VIII-2 shows the hood being pulled up into place on the buckstays. Figure VIII-3 shows the hood with three of its five full sections in place. On each side of each section, strips of magnetic tape were fastened to hold the section in place during installation. These magnetic strips, which show along the section edges in Figure VIII-1, hold the hood sections to the buckstays rather well until they encounter high temperatures. With high temperatures, the 1.6-mm (16-gage) metal used in the hood sections tends to warp and pop the metal back in spite of the magnetic strip.

To hold the hood more firmly in place during operation, and to avoid leakage of gases around the edges of the hood, special clamping devices were fashioned to attach to the outside flange edge of the buckstay. These clamps have angle-iron extensions welded to them so that when the clamp is applied to one side of the hood section, the extension presses firmly against the entire height of the section edge to hold it tightly in place. Figure VIII-4 shows one of these clamps in open position, not yet applied to the hood section. Figure VIII-5 is a view of the clamp in closed or applied position. Figure VIII-6 is an overall view of a clamp in closed position against one of the section edges.

Figure VIII-7 is a view of the top plate which fits between the buckstays and provides the top enclosure for the space enclosed by the hood. This view shows the pressure-tap tube (between the man's hands) used to monitor pressures within the space around the coke-oven door and between the buckstays. The 10.2-cm (4-inch) gas-exit port is shown. The length adjustment which enables the plate to be put into place past protruding objects can be seen on the left end. Railing hooks attached to the top of the plate by stiff coil springs serve to support the plate over its span during sampling runs.

Figure VIII-8 shows the under side of the top plate as viewed from a point looking up between the buckstays in the direction that must be taken by gases escaping from around the coke-oven door and by the introduced air which sweeps upward over the door.

The pipe that carries air to the bottom of the hood cavity is visible in the upper righthand corner of Figure VIII-8. This same air is shown in Figure VIII-9 before installation. Here it is shown attached to the compressed-air supply line which contains a pressure gage, pressure regulator, and a filter.

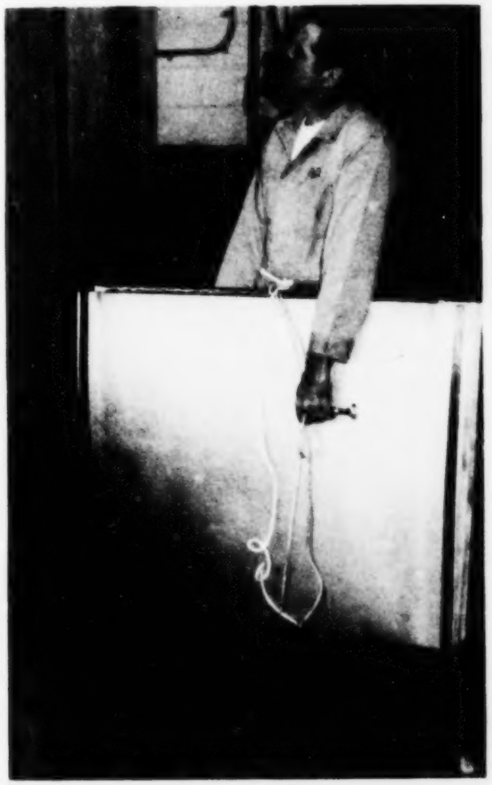

FIGURE VIII-1. COKE-OVEN HOOD HELD BY RESEARCHER (D. HUPP) IN FOLDED POSITION PRIOR TO MOUNTING ON BUCKSTAYS OR SIMULATED COKE OVEN. MAGNETIC STRIPS SHOW ON BACK OF HOOD SECTION.

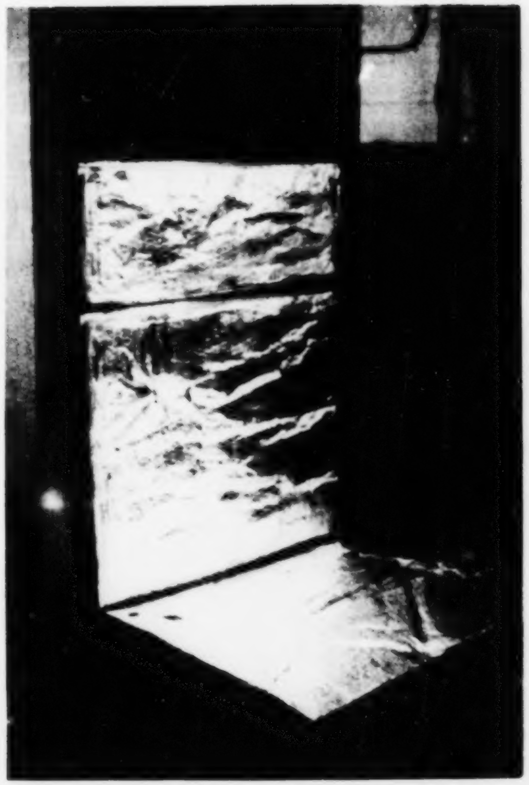

FIGURE VIII-2. HINGED HOOD BEING PULLED INTO PLACE ON BUCKSTAYS

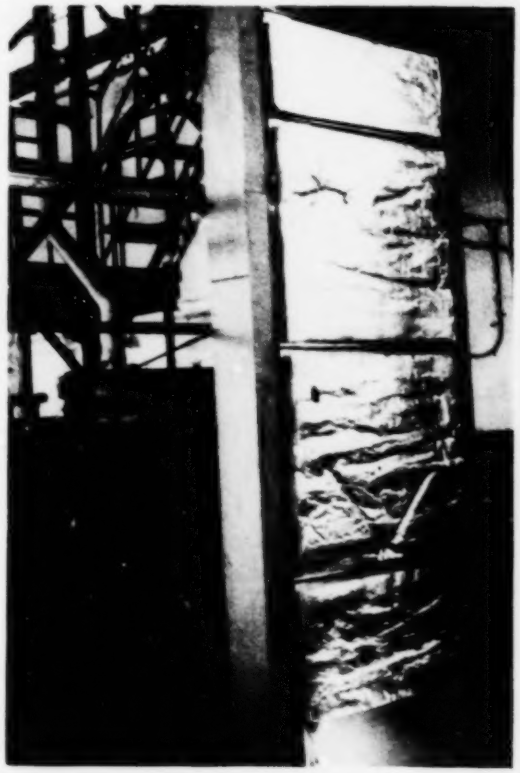

FIGURE VIII-3. HOOD PULLED UP TO COVER OVER HALF OF CAVITY BETWEEN BUCKSTAYS

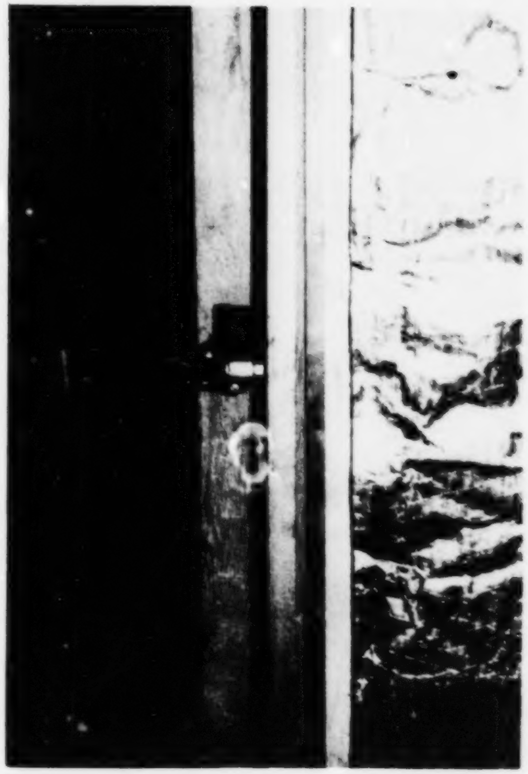

FIGURE VIII-4. HOOD CLAMP ATTACHED TO BUCKSTAY FLANGE AND FIXED IN OPEN POSITION

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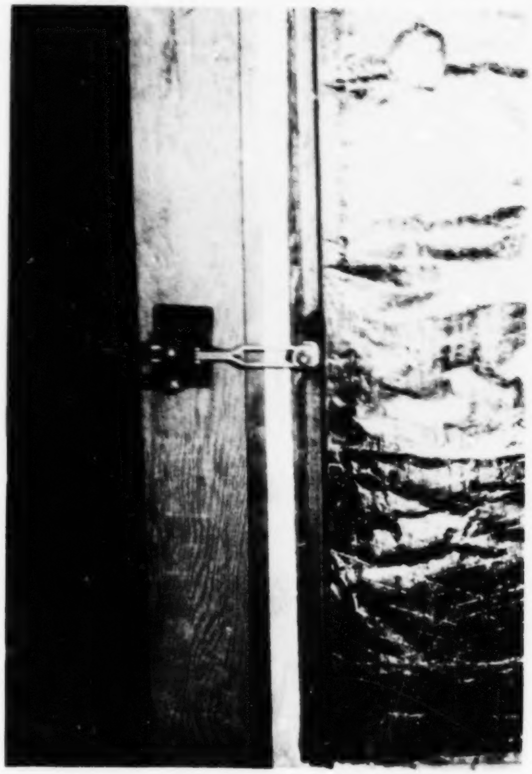

FIGURE VIII-5. HOOD CLAMP ATTACHED TO BUCKSTAY FLANGE AND FIXED IN CLOSED POSITION

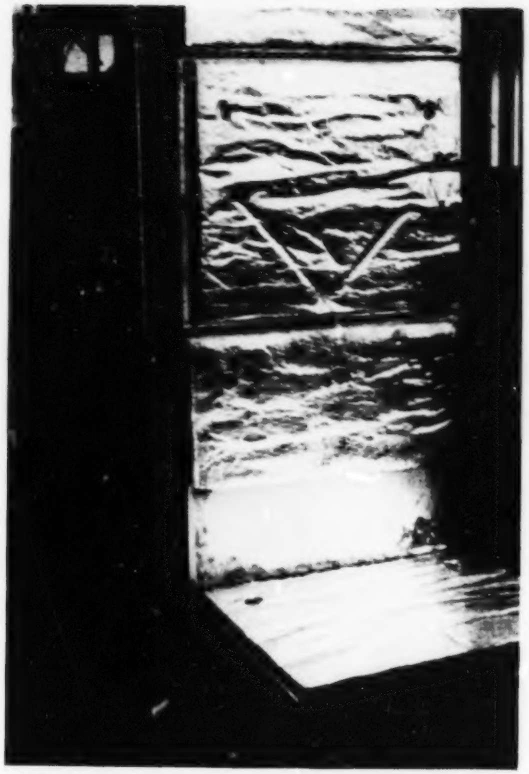

FIGURE VIII-6. OVERALL VIEW OF HOOD CLAMP IN CLOSED POSITION

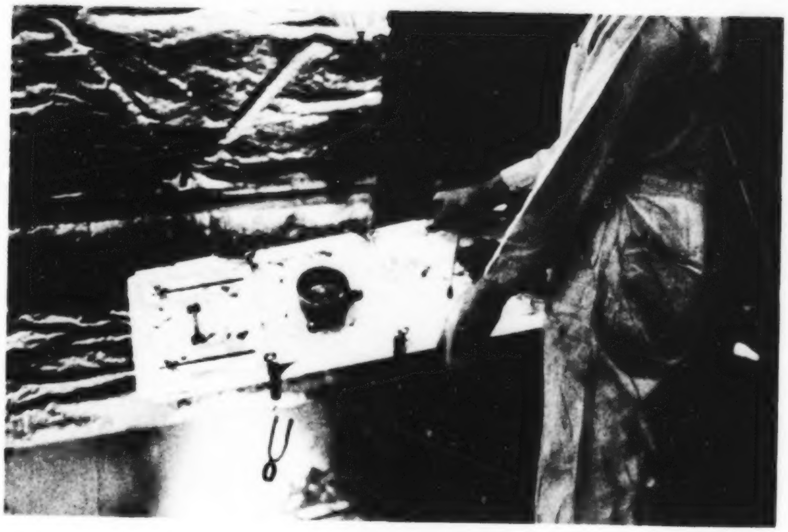

FIGURE VIII-7. VIEW OF HOOD-TOP COVER PLATE SHOWING PRESSURE TAP, GAS-EXIT PORT, LENGTH-ADJUSTMENT FEATURE, AND PLATE-SUPPORT HOOKS

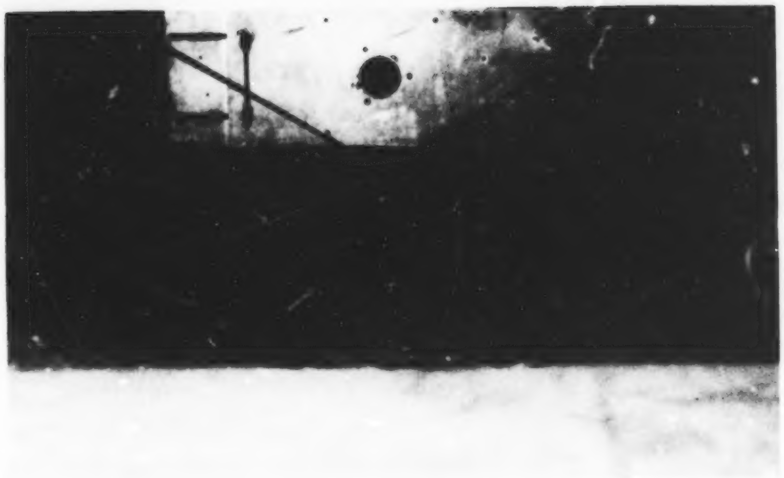

FIGURE VIII-8. HOOD-TOP COVER AS VIEWED LOOKING UPWARD FROM BETWEEN BUCKSTAYS

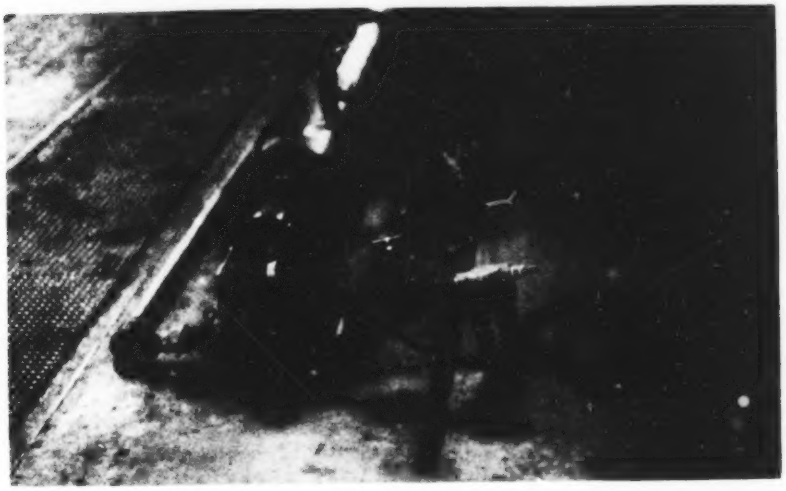

FIGURE VIII-9. HOOD AIR SUPPLY BEFORE INSTALLATION. SHOWN ATTACHED TO COMPRESSED-AIR SUPPLY LINE CONTAINING PRESSURE GAGE, PRESSURE REGULATOR, AND FILTER.

During emission-measurement runs, sampling equipment was located on top of the coke-oven battery at the charging-port level. Figure VIII-10 is an overall view of the sampling system. It extended from the top of the hood top-cover plate to the main blower which exhausts gases from within the hood. From left to right, Figure VIII-10 shows the 10.2-cm (4-inch) flexible line that connects the top plate to a 10.2-cm metal duct. A 5.1-cm (2-inch) flexible line carries a gas stream withdrawn from the hood exhaust stream and carries it to high-volume (Hi-Vol) samplers. (This equipment is manufactured by General Metals Works, Cleves, Ohio.) This 5.1-cm flexible line can be switched from one sampler to the other in about 10 seconds. Downstream of the point where the air sample is withdrawn for the Hi-Vol sampler, an orifice is located in the 10.2-cm duct so that measurement can be made of the volume of gas that flows past (bypasses) the Hi-Vol samplers. Downstream from the orifice, the duct includes a damper that can be adjusted to control the flow coming from the space within the hood. Immediately downstream from the damper there is in the duct a "T" which can serve as a balance in controlling flow. The leg of the "T" contains a damper which can vary the amount of air pulled to the blower from outside. The blower appears at the extreme right of Figure VIII-10.

Figure VIII-11 is a closeup view of the Hi-Vol samplers and metering equipment. On the front of the Hi-Vol on the right is an adsorber column which is attached during tests by tubing to the Hi-Vol sampler downstream from the filter. A sample of about 0.021 m^3 (0.75 ft^3) per minute is drawn through the adsorber by the pump shown to the left of the gas meter in Figures VIII-10 and VIII-11. Tubing during tests is arranged so that flow from the adsorber goes to the pump and then through the gas meter.

The open door on the Hi-Vol reveals the sampler's flow recorder. The inclined manometer at the top of the instrument board to the right of the Hi-Vol connects by tubing with the pressure tap on the hood-top cover plate shown in Figure VIII-7. This manometer is used in monitoring static pressure beneath the hood. The manometer on the left side of the board records the pressure of the flow transducer on the Hi-Vol, permitting the sample flow to the sampler filter to be kept constant. The manometer on the right side of the board measures the pressure differential across the flow orifice, thus monitoring the flow in the duct downstream from the flow line to the Hi-Vol.

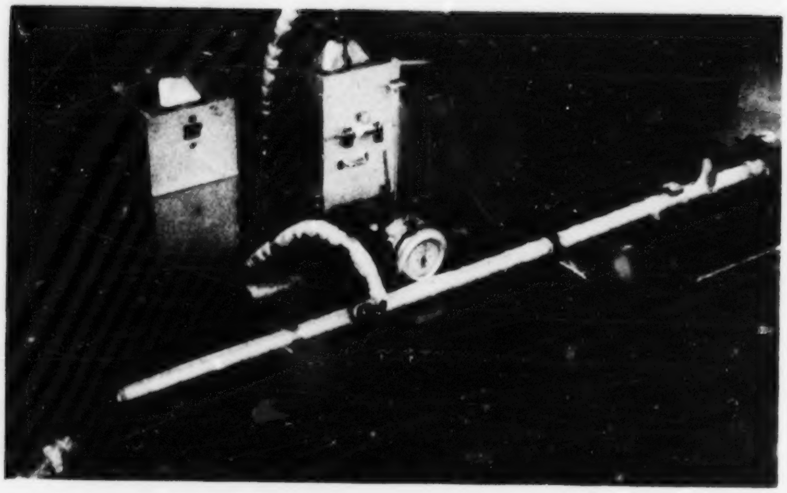

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FIGURE VIII-10. OVERALL VIEW OF SAMPLING EQUIPMENT USED IN TAKING SAMPLES AND MAKING MEASUREMENTS

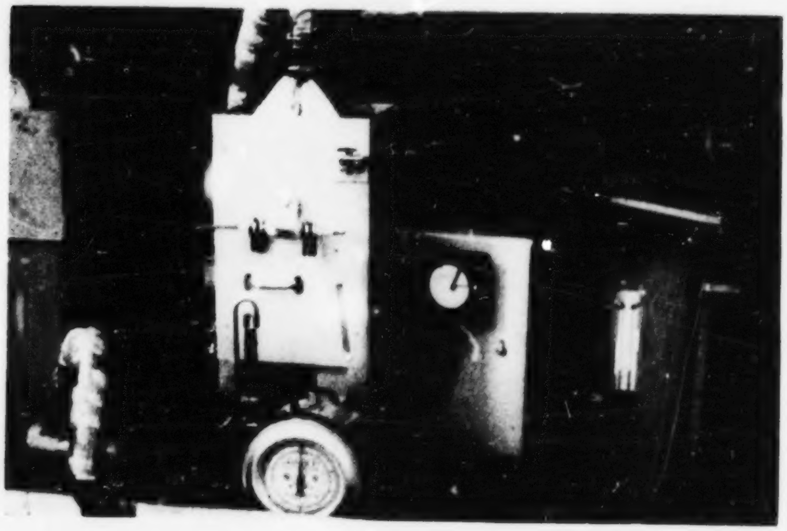

FIGURE VIII-11. CLOSEUP OF HI-VOL SAMPLER AND ITS FLOW RECORDER, ADSORBER COLUMN WITH FLOW METER AND PUMP, AND THE MANOMETER BOARD

A critical-flow orifice in the compressed-air line enabled the test team to put a measured quantity of air down into the hood cavity between the buckstays. This air plus gases leaking from around the coke-oven door constituted the total gas flow from the hood into the 10.2-cm (4-inch) duct. A known volume of gas was drawn off to the Hi-Vol sampler, and the remaining gas volume that flowed through the orifice in the 10.2-cm line accounted for total gas flow. Thus, orifice-flow volume plus Ni-Vol volume minus compressed-air volume equaled volume of leakage from around the coke-oven door.

Figure VIII-12 is a view of the Hi-Vol sampler with the inlet cap and filter holder tipped back showing the coarse mat and regular glass-fiber filters used in preliminary laboratory and coke-oven-battery test runs.

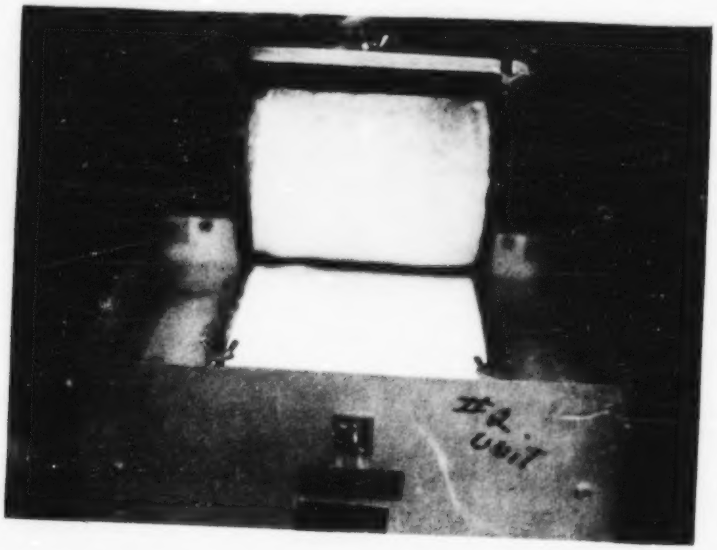

FIGURE VIII-12. HI-VOL SAMPLER WITH COARSE (UPPER) AND REGULAR (LOWER) FILTERS BEING INSTALLED

Laboratory Test Runs

To try out the sampling hood in the laboratory, a mockup of a coke oven and its buckstays was built to full scale. The mockup was built of plywood except for metal braces and metal strips on the buckstays to simulate the metal of real buckstays. Figures VIII-1 through VIII-8 show parts of the mockup with Figure VIII-8 revealing the metal braces used to strengthen the wooden buckstays. Figure VIII-2 shows the metal buckstay strips clearly.

As a rough check on the system, a 3-minute smoke bomb was set off on the floor inside the hood. This bomb released more particulate matter than a regular filter in the Hi-Vol could handle. The passages of the filter were plugged in about 1 minute, as evidenced by the flow through the filter dropping to zero.

Although the concentration of particulates provided by a smoke bomb may be greater than would be encountered ordinarily with leakage from a coke-oven door, provision was made to handle such a concentration. This was accomplished by adding a second Hi-Vol sampler with provision for switching the gas line rapidly from one sampler to the other. The switch can be carried out within 10 seconds.

The second approach to handling a very high concentration of particulate matter through the Hi-Vol sampler was to add a coarse glass-fiber mat ahead of the normal filter (which has an efficiency of over 99 percent for 0.3-micron particle sizes and larger). With the coarse filter in operation ahead of the regular filter, another smoke bomb test was run. With the two filters in use, the Hi-Vol sampler operated throughout the full 3-minute life of the bomb without any measurable decrease in flow through the sampler.

Coke-Plant Test Run

It was recognized that although the system performed satisfactorily in the laboratory, operation in the field was the purpose of the system. Therefore, a single trial run was performed at an operating battery.*

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* Under a separate contract, EPA funded additional testing of this equipment. The results of this program are not available at this time.

The objective of the trial run was to operate the collection system on a producing coke oven to determine if major modification was required before making test runs to evaluate new oven-door sealing concepts.

Permission for a trial run was granted by Empire-Detroit Steel Division, Detroit Steel Corporation, Portsmouth, Ohio. The test site was a high-bench Koppers coke-oven battery that was built in 1964. Door leakage from these ovens is generally light compared with other ovens in the industry. Figure VIII-13 is a view of Ovens 1 through 3 from the coke side of the battery. Figure VIII-14 is a view looking from Oven 1 toward the coke received car on the coke side. It illustrates how the buckstays on this oven extend down to the bench level.

Specific items that were listed for checking were enumerated as follows:

(1) Whether or not the filter system could be operated for extended periods without particulate emissions overloading the filters.

(2) Operation of adsorption columns with samples taken after the high-volume filters. These samples were wanted for quantitative and qualitative analysis of the emission gases.

(3) General functioning of the hood and sampling system when mounted on the buckstays of an operating coke oven.

(4) Temperature of the hood surface to determine if insulation was needed on the outside surface. Concern had been expressed regarding the possibility of condensation on the inside surface of the hood.

It was found that the coarse and regular filters handled with ease the particulate emissions encountered. In this test, the coarse filter probably would not have been needed over the 2.5-hour trial run.

The adsorption column performed well throughout the run. Flow was held consistently at about 0.018 m^3 (0.65 ft^3) per minute and a total sample of 2.45 m^3 (86.5 ft^3) was passed through the adsorption column.

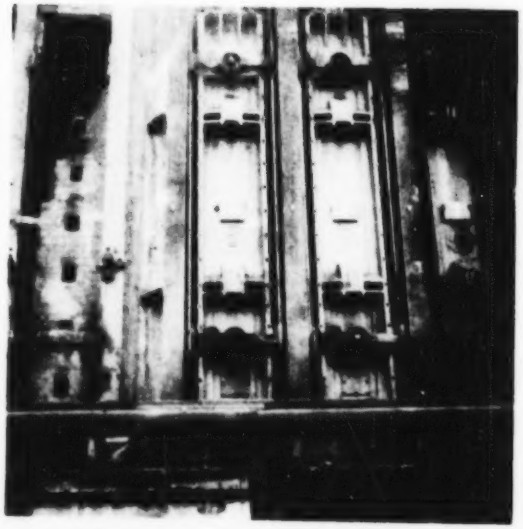

FIGURE VIII-13. KOPPERS HIGH-BENCH COKE-OVEN BATTERY FROM COKE SIDE OF BATTERY

FIGURE VIII-14. OVEN DOORS AND BUCKSTAYS ON COKE SIDE OF BATTERY

It was found that the hood covering the buckstays might cause abnormal heating of the oven door. At 3 hours and 45 minutes into the coking cycle, the door-surface temperature was about 65 C (150 F) above the temperature of another oven that was charged 15 to 20 minutes after the test oven. Temperature measurements on the coke-end doors taken 10 to 15 minutes after the hood was removed were 220 C (430 F) for the test-door surface and 150 C (300 F) for the surface of a door used in comparison. Similar measurements made on the pusher end of these same ovens gave 150 C (300 F) for the test oven and 170 C (340 F) for the comparison oven. Thus, there is variability in temperatures recorded on door surfaces from oven to oven.

Temperatures of 80 C (175 F) to 85 C (185 F) were recorded on the outside surface of the hood. This led to the conclusion that for future use the insulation should be removed from the outside surface of the hood.

In general, the test at the coke-oven battery showed that this system for collecting and measuring emissions of particulates can be used to evaluate and compare new methods for sealing coke-oven doors. The approach and equipment appear satisfactory for about the first 2 hours of coking operation. For longer periods of measurement, intermittent application of the hood or other means of preventing significant increases in door temperature should be considered.